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THE FUMING OF LEAD BLAST FURNACE SLAG FOR BRUNSWICK SMELTING, BELLEDUNE, NEW BRUNSWICK

G.M. Denton and G. Assis
Mintek, Pyrometallurgy Division

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The Fuming of Lead Blast Furnace Slag
for Brunswick Smelting,
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Minister of Natural Resources

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Randburg, South Africa

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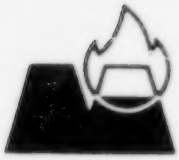

MINTEK

Specialists in mineral and metallurgical technology

COMMUNICATION

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THE FUMING OF LEAD BLAST FURNACE SLAG FOR BRUNSWICK SMELTING

by

G M Denton and G Assis

10 December 1997

200 Hans Strijdom Drive
RANDBURG
South Africa

THE FUMING OF LEAD BLAST FURNACE SLAG FOR BRUNSWICK SMELTING

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10 December 1997

PYROMETALLURGY DIVISION

Chief Investigator	:	G M Denton
Co-Investigator	:	G Assis
Director of Division	:	T R Curr
Technical Objective	:	405
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Date		10 December 1997

Synopsis

Testwork has been successfully conducted on the smelting of zinc-containing lead blast furnace slag produced by Brunswick Smelting in a DC-arc furnace pilot plant at Mintek. The main objectives were to:-

- obtain a direct comparison between the chemical behaviour of Brunswick and Doe Run lead blast furnace slag (LBFS) by duplicating operating parameters such as power, current, voltage, temperature, slag depth and carbon to LBFS, ZnO ratio.
- determine the effect of lowering operating temperature on kinetics, alloy production, the energy consumption and zinc extraction.
- determine the effects of power and current density and any associated induced mixing on fuming kinetics.
- determine the effects of increased slag liquidus temperature (via dolomite addition) on zinc extraction and refractory wear.
- determine major and minor elemental deportment to the various product streams for the various operating scenarios.

The LBFS supplied was analysed to contain 16.2 per cent Zn with a basicity ($[MgO + CaO]/SiO_2$) of 0.84. A South African coke containing approximately 79 per cent fixed carbon was used as the reductant.

61 Smelting/tapping operations involving some 57 tons of feed slag were conducted producing 3 tons of alloy, 44 tons of discard slag and 12 tons of zinc fume. From the results obtained the following conclusions can be drawn:

- For similar operating parameters the chemical behaviour of Brunswick and Doe Run LBFS (with basicity corrections) is directly comparable i.e. the degree of zinc extraction is primarily dependent on the operating temperature.
- An operating temperature in excess of 1450°C and a coke addition of approximately 5 per cent is required in order to produce a discard slag containing 3 per cent or less zinc oxide. Energy requirements are also similar to those obtained with Doe Run LBFS at 0.7 MWh/t feed (excluding furnace heat losses).

- The production of metallic iron cannot be prevented (30-40kg Fe/t slag) and it appears to be accelerated under conditions of excess carbon at lower operating temperatures.
- Increasing the power and current density had no apparent deleterious effect on the operation at the pilot plant scale.
- Zinc fuming rates of as high as 192kg Zn/hm^2 were achieved together with acceptable overall zinc extraction.
- Very little information can be drawn from the limited amount of work done with dolomite addition, except that MgO addition does not appear to affect the ZnO versus temperature relationship.
- The furnace refractories were seen to perform well although no protective slag freeze lining was encountered.

It is recommended that testwork advance to a larger pilot scale in order that combined operation with an ISP lead splash condenser can be evaluated and scale-up parameters can be obtained en-route to commercialisation.

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1 BACKGROUND

Brunswick Smelting a division of Noranda Mining and Exploration Inc. have a significant amount of lead blast furnace slag (LBFS) containing about 13 per cent zinc and 4 per cent lead as a stockpile at their lead smelter - refinery in Belledune, New Brunswick. The potential also exists to utilise high zinc containing lead concentrates and by so doing increase the zinc content of current slag production to as high as 18 per cent. The current slag produced is not at present considered a hazardous waste in Canada, according to the CGSB leachate extraction test.

Mintek and the Doe Run Company have jointly carried out extensive investigations aimed at developing a commercially viable process to treat LBFS and render it environmentally acceptable for disposal (according to USA EPA TCLP standards) and at the same time produce Prime Western grade (PW) zinc. Solid slag was planned to be fed to the sinter plant as a diluent while molten slag at 1150°C from the lead blast furnace would be fed to a slag treatment plant.

Pilot plant testwork was first conducted during 1989 to 1990 at Horsehead Resources Development on a flame reactor. Follow-up testwork conducted by Tetronics Research and Development (TRD) in a DC-arc furnace, operating at power levels of 300 to 600kW, coupled to a zinc splash condenser showed that a disposable slag could be produced, however only 32 per cent of the total zinc input was recovered as zinc metal from the condenser. After further techno-economic evaluations of existing and emerging technologies it became evident to Doe Run that Mintek's Enviroplas™ process (a DC-arc furnace and a lead splash condenser) could provide a cost effective alternative process for the treatment of LBFS.

The proposed slag treatment plant would involve the feeding of a molten slag to a DC-arc furnace coupled to an Imperial Smelting Process Ltd (ISP) lead splash condenser.

Between 1992 and 1996 various testwork programmes at scales ranging from 100kW to 1.5MW were conducted at Mintek in order to determine the conditions to maximise zinc extraction, fuming and condensation for Doe Run lead blast furnace slag. All information related to this testwork has been fully documented by way of reports and distributed to

Brunswick Smelting[1-8]. In addition a preliminary pre-feasibility study was conducted for Brunswick Smelting[9] on the recovery of zinc metal from their slag which indicated a project with good potential.

In order to assess the amenability of LBFS generated by Brunswick Smelting to the Enviroplas™ process, a testwork programme was conducted as detailed in this report.

2 CAMPAIGN OBJECTIVES

The six day campaign was preceded by a 24 hour warm-up period during which 500kg of iron was melted down. A nitrogen purge was provided and the furnace was run at a pressure slightly greater than atmospheric to prevent the ingress of air into the furnace.

After the warm-up the actual testwork commenced, with the following prime objectives:

- Determine the effect of lowering operating temperature on kinetics, alloy production, energy consumption and zinc extraction.

- Obtain a direct comparison between the chemical behaviour of Brunswick and Doe Run lead blast furnace slag (LBFS) by duplicating operating parameters such as power, current, voltage, temperature, slag depth and carbon to LBFS, ZnO ratio.

- Determine the effects of power and current density and any associated induced mixing on fuming kinetics.

- Determine the effects of increased slag liquidus temperature via dolomite addition, on zinc extraction and refractory wear.

- Determine major and minor elemental deportment to the various product streams for the various operating scenarios.

The initial operating parameters proposed were as follows:

Power:	725kW
Voltage:	250V
Current:	2.90kA
Current Density:	2.4 kA/m^2
Energy:	0.70kWh/kg LBFS
Slag Feed Rate:	679kg/h
Fixed Carbon Addition:	0.24kg/kg ZnO fed
Batch Size	1000kg
Tap to Tap Time:	~2h
Zn Fuming Rate	70kg/hm^2

Abovementioned initial parameters such as carbon addition and energy requirements could be varied in order to achieve the desired operating temperature (1350°C) and residual ZnO content in the slag i.e. of the order of 4 per cent. The remainder of the campaign has been summarised as a flowsheet and can be seen in Appendix A.

After a one tonne batch had been charged to the furnace the furnace contents were tapped by oxygen lancing the slag taphole. The metal was tapped periodically (typically after four or five slag taps) so that a fairly constant metal level was maintained throughout the campaign.

The metal was tapped into a standard ladle lined with refractory material, covered with a mould wash, whilst the slag was tapped into an unlined steel ladle. Spoon samples of the slag were taken from which representative samples were obtained, milled (Ziebtechnik) and submitted for on-line analysis by the Analytical Division at Mintek. The metal spoon samples were retained for post campaign analysis.

On-line analysis of the slag, which takes approximately one hour, provided an indication of the bath chemistry thereby facilitating changes to the recipe during the campaign. The slag was analysed for: Al_2O_3, SiO_2, FeO, Cr_2O_3, CaO, MgO, ZnO, CuO and PbO while the metal was later be analysed for Fe, Cu, Pb, Cd and As.

Slag and metal temperatures were taken by means of an optical pyrometer, assuming an emmisivity of 0.7 for both the metal and slag. The feed to energy balance was adjusted to give the desired operating or tapping temperature. Energy losses through the furnace side-walls and roof were calculated at regular intervals and incorporated into the energy balance.

Weighing of the product masses (slag, metal and fume) was done in order to provide information for a detailed mass balance at the end of the campaign. The fume and dust that accumulated in the gas processing plant was removed, weighed and sampled periodically throughout the campaign. The fume mass and analysis can be used to project approximate dross masses and product zinc masses and analyses as if the furnace off-gas had passed through the condenser.

After the campaign the furnace interior was examined and measurements of the side-walls were taken to facilitate a qualitative description of the refractory wear. Samples of slag/metal heel were collected and analysed and the results incorporated into the overall mass balance.

All the relevant process and operating data was recorded and logbooks and logsheets completed by the shift team.

3 EQUIPMENT DESCRIPTION

A schematic diagram of the pilot plant is shown in Figure 1.

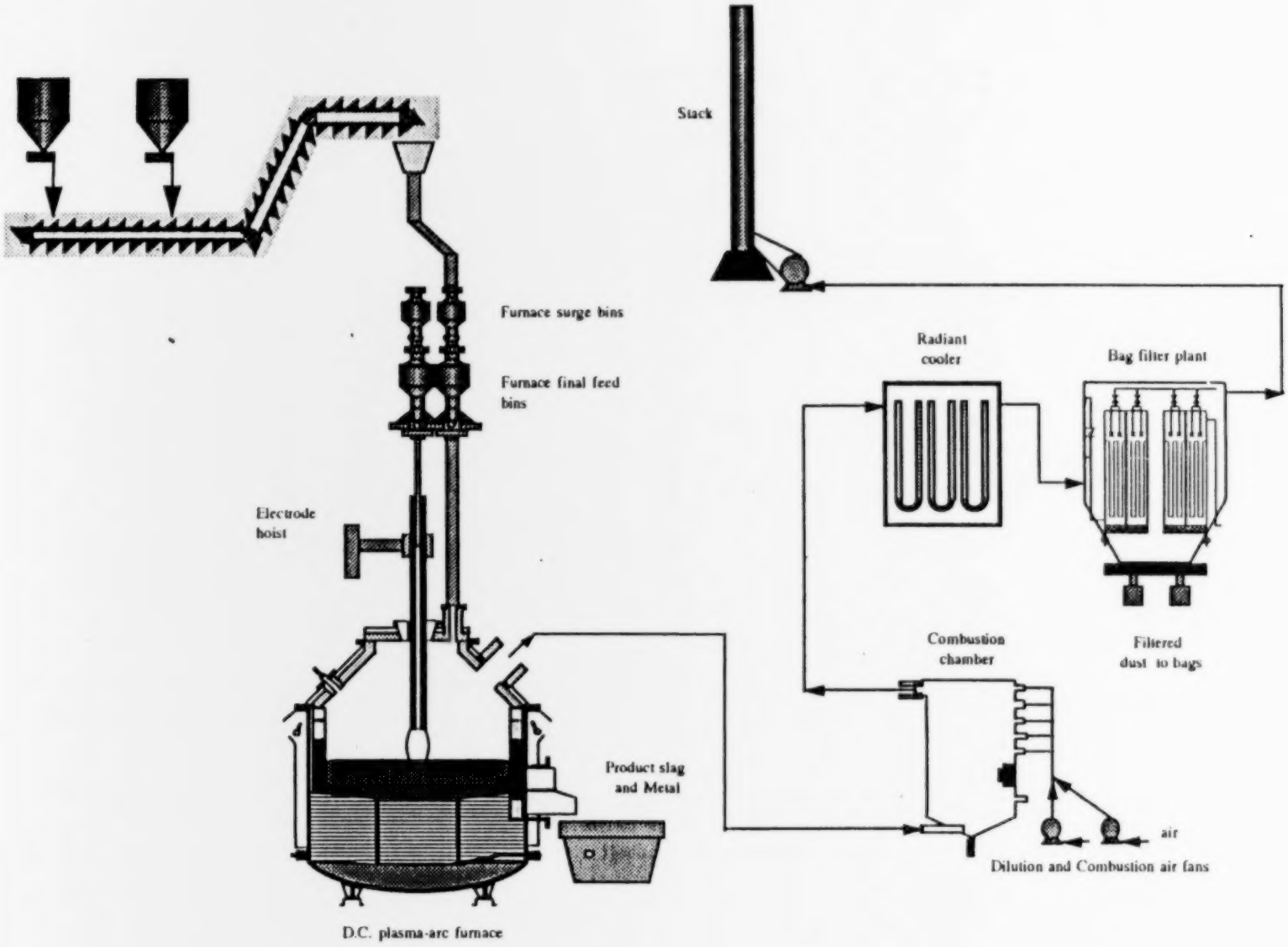


Figure 1 Schematic diagram of Bay 2 pilot plant

3.1 Feed System

The feed system comprised two parts, namely a batching plant (Figure 2) and a final feeding arrangement (Figure 3). The raw material batching plant consisted of 8 primary feed hoppers varying in size (100ℓ to 1500ℓ) and capacity (150kg to 6000kg). The primary hoppers fed via variable speed belt feeders onto a pocket conveyor which then delivered the material through a 3 way splitter to the final feed arrangement.

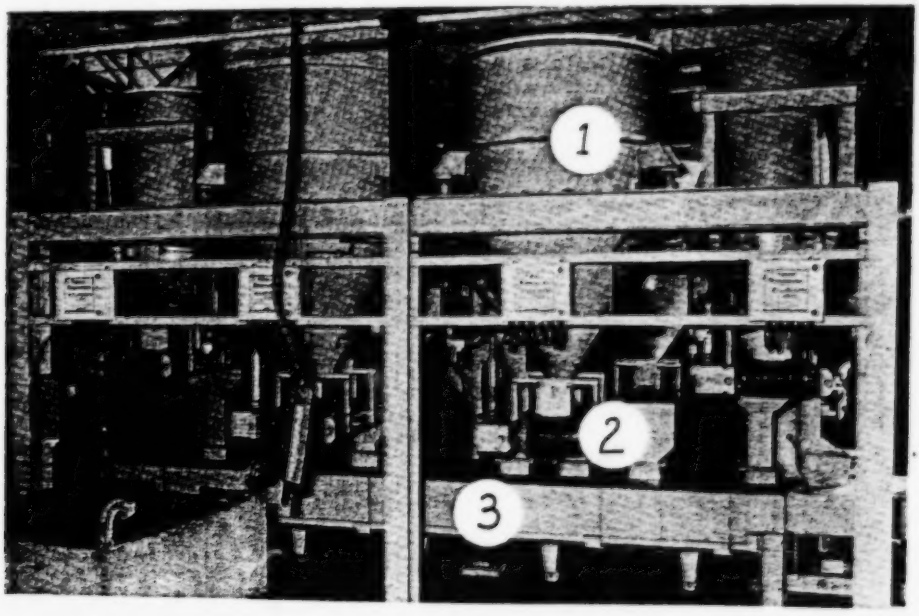


Figure 2 Primary feed system

1. Feed bin; 2. Belt feeder; 3. Conveyor belt

The final feed system consisted of two surge hoppers (250ℓ with a 750kg capacity and 125ℓ with a 300kg capacity) which received material directly from the pocket conveyor. The two surge hoppers then deliver the material, via pneumatically actuated slide valves (to provide a gas seal), to 2 final feed hoppers located directly below.

The two final feeders delivered material, via variable speed screw feeders, to the furnace through three feed ports located in the furnace roof radially around the electrode (side feed).

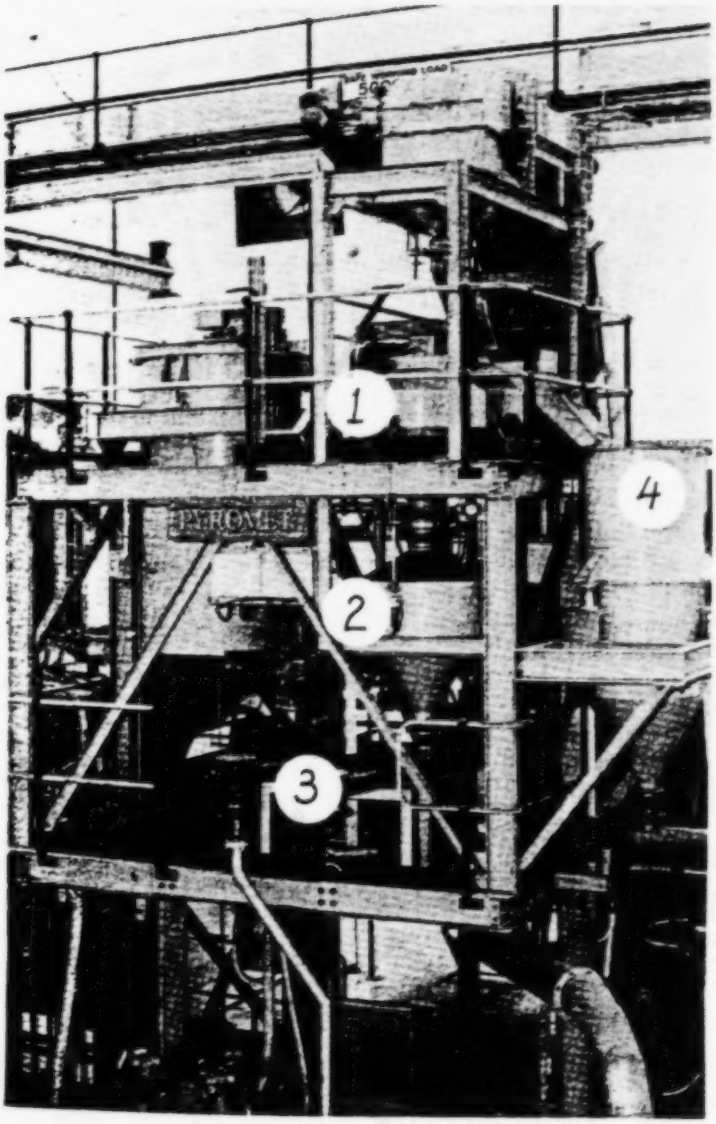


Figure 3 Final feed system

1. Surge hopper; 2. Final feed bin for furnace; 3. Screw feeder; 4. Final feed bin for premelting furnace (not utilized).

The hoppers rested on load cells and were provided with dedicated controllers that were situated in the control room. The feeder controllers are provided with a feedrate setpoint by the SCADA (supervisory control and data acquisition) system but may also be operated manually.

3.2 Furnace

The furnace consisted of a refractory lined water cooled mild steel shell of internal diameter of 1242mm, a conical roof, a flat roof and a dome shaped base. The furnace shell has an internal diameter of 1500mm. The shell was lined with magnesia-chrome refractory bricks (D60/100) produced by Vereeniging Refractories, Table 1. An anode consisting of mild steel pins welded onto a steel plate was installed in the base of the furnace shell in order to provide an electrical connection through the refractory lined furnace hearth. The furnace was employed with film water cooling on the side walls. The flat roof contained the feed ports and the central entry port for the graphite electrode (125mm in diameter). The off gas port was located on the conical roof. The roofs were lined with a 95% alumina castable.

Table 1 Chemical analyses of D60/100 magnesia chrome refractory bricks in mass %

% SiO_2	% Al_2O_3	% Fe_2O_3	% CaO	% MgO	% Cr_2O_3
1.6	7.5	10.1	1.4	59.2	20.2

Max T	1750°C
Bulk density	3225 kg/m^3
Cold crushing strength	38.0 MPa
Thermal conductivity (1000°C)	2.6 W/mK
Thermal expansion (20°C – 1000°C)	1.0%

The dimensions of the furnace interior before the campaign are given in the schematic diagram shown in Figure 4. A single layer of refractory bricks was utilized for lining the shell side walls and a double layer used next to the hearth to contain the metal layer. The hearth was lined with chrome castable below the anode plate and Ankerhearth (a high magnesia dry ramming material) above the anode plate, Table 2. Two tapholes were employed: one for tapping metal positioned 50mm above the hearth and the second for tapping slag positioned 200mm above the metal taphole. A water cooled copper block with a 80mm central hole was attached to the slag taphole block in order to minimise refractory wear of the taphole area. The metal taphole diameter was 25mm.

K-type thermocouples were inserted 50mm deep into the furnace refractory to monitor lining temperatures throughout the campaign.

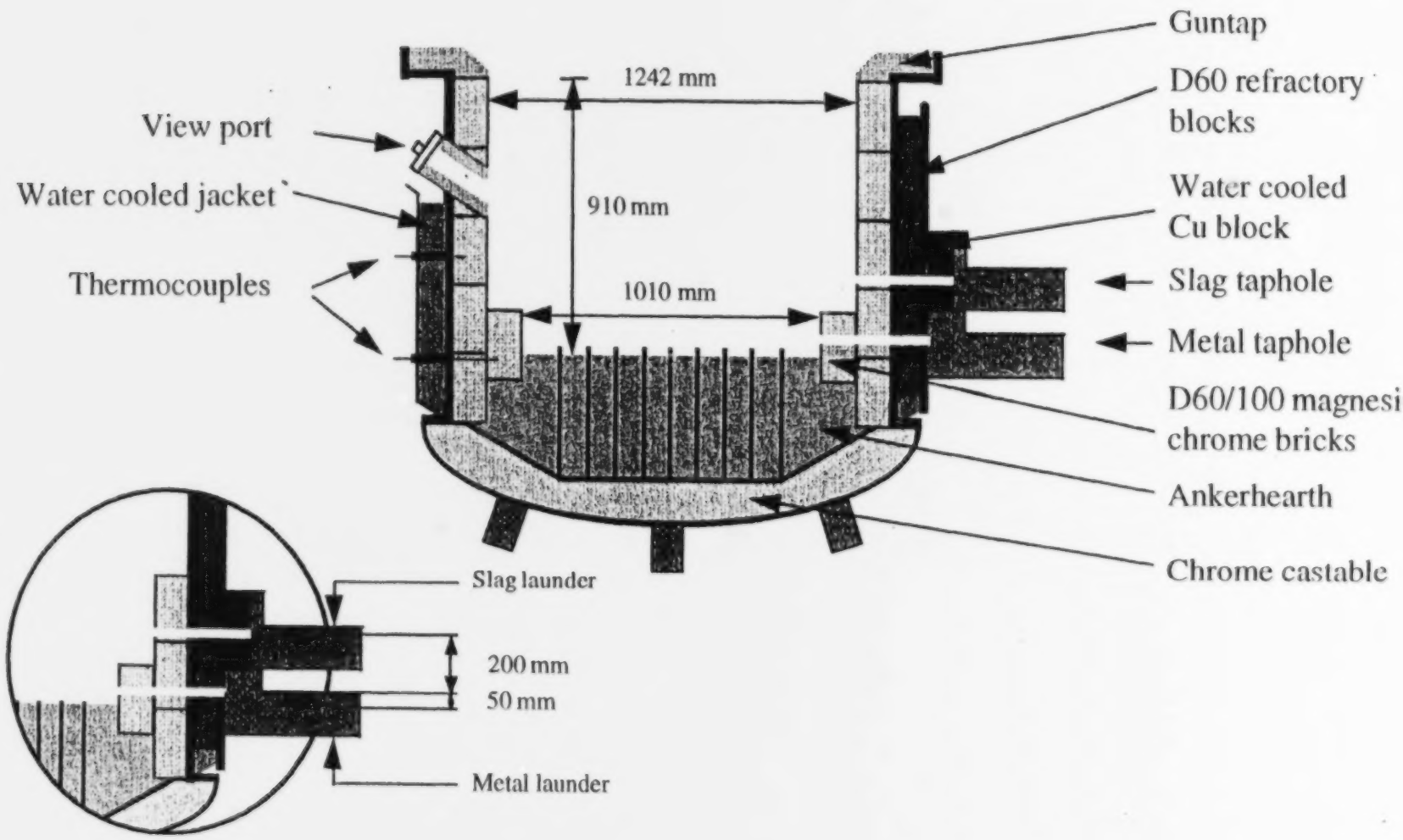


Figure 4 500 – 1000kW d.c. furnace – lining

Table 2 Chemical composition of magnesia hearth refractory – "Ankerhearth NN25"

% SiO_2	% Al_2O_3	% Fe_2O_3	% CaO	% MgO
0.7	0.5	3.5	18	77

Max T	> 1750°C
Bulk density	2700 kg/m^3 @ 200°C
Cold crushing strength	> 10 MPa @ 1300°C
	> 20 MPa @ 1600°C

3.3 Tapping Trays

The product slag and metal tapped was allowed to flow into mild steel pots and refractory lined ladles respectively. The slag pots had a volume of approximately 350ℓ and the refractory lined ladle volume was approximately 150ℓ. Two of these receptacles were arranged in a cascade during tapping.

After tapping, the ladles were allowed to cool until a solid crust had formed, after which they were taken by forklift to a cooling area and allowed to cool for 8-12 hours by which time the ladle was deemed safe to tip or empty.

After the specified cooling period the cool ladles were transported, again by forklift, to the breaking out area where they were tipped. The slag was thereafter manually broken into smaller pieces and stock piled.

3.4 Off-gas System

The gas generated in the furnace was expelled through an off-gas port into the gas extraction system. The gas extraction system comprised water-cooled ducting, a refractory lined combustion chamber, more water-cooled ducting, a "trombone" gas cooler, a reverse-pulse bag filter, a fan and a stack.

Combustion of the furnace off-gases, with excess air, occurred in the gas extraction ducting leading to the combustion chamber (Figure 5). The gas extraction system included a water-cooled duct leading off from the furnace, drawing furnace exhaust gases and fumes out of the furnace. The water-cooled ducting carried the off-gas to a combustion chamber which consisted of a refractory-lined cylindrical vessel about 6m high, 1,25m in diameter (outside diameter) and with a 250mm thick lining. The top of the combustion chamber was fitted with a safety valve designed to open when the pressure inside the combustion chamber exceeded 150mm water gauge.

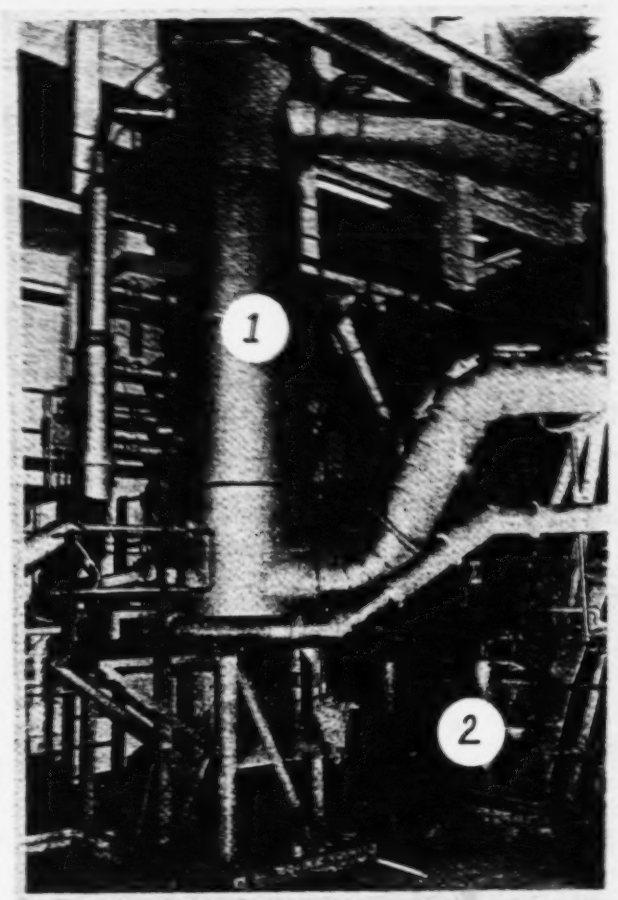


Figure 5 Combustion chamber

1. Combustion chamber; 2. Condenser body (not utilized)

The combustion chamber was followed by additional ducting which conveyed the combusted furnace off-gas to the gas cooling and cleaning plant. The gas cooler and bag filter are shown in Figure 6. The cooler consisted of a radiant "trombone" gas cooler. Final trimming of gas temperature before entering the bag filter was achieved by the introduction of dilution air (at ambient temperature). The cooled gas stream then entered the reverse pulse gas filter and the filtered gas stream was expelled to the atmosphere. The gas flowrate or furnace suction was controlled by a hydraulically operated damper situated between the radiant cooler and the bag filters. The maximum design flowrate of the bag filter was 27 000m^3/h.

Filtered solids were discharged via screw feeders into fume collection bags. The fume bags were changed from time to time and the fume collected was weighed and sampled.

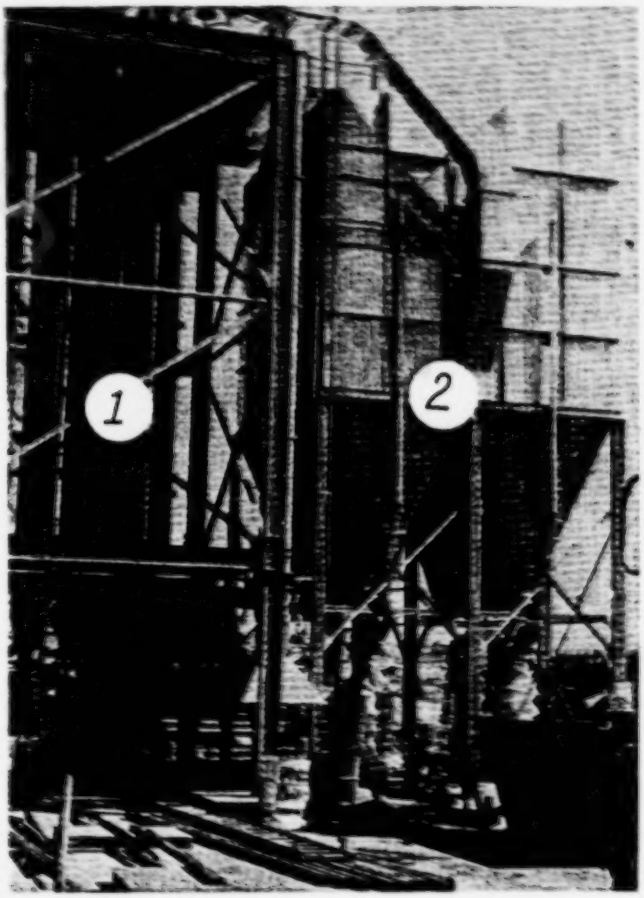


Figure 6 Gas cooler and bag filter

1. Gas cooler; 2 Bag filter

3.5 Power Supply

The power supply consisted of an 11kV vacuum breaker, 2 isolators, 2 contactors, 2 x 2.8MVA transformers and 2 x 5kA DC thyristor rectifiers. The vacuum breaker is designed to break under load should a transformer fault exist and cannot be remotely opened or closed. An isolator and contactors provide the electrical isolation between each transformer and vacuum breaker. The contactors are designed to break under load and can be opened and closed remotely by the operator while the isolator must be manually operated.

The power supply can be configured to serve either one or two furnaces by a physical change of the furnace busbar configuration. Thus each transformer and its respective rectifier can be operated independently in 6 pulse mode to provide power to two installations, each with a 500V, 5kA limit. In combined or 12 pulse mode, limits of 500V and 10kA are set.

Each transformer has either a parallel or series selection together with a two tap position option. Thus there are two tap positions for parallel and similarly two positions for series operation, making a total of 4 voltage operation regimes. It is important to note that in the combined configuration the respective tap settings on each transformer need to be identical.

Series/parallel or tap changing must only be done with the transformer contactor off. This is ensured by means of a key interlock.

The thyristor rectifiers are cooled by a dedicated deionised water cooling circuit while busbar water cooling utilizes pond cooling water.

The power supply was initially connected in 6 pulse mode for the testwork but later connected in 12 pulse mode thereby able to deliver a maximum of 5MW at 500V and 10kA.

3.6 Instrumentation and Control

The control system allowed the furnace and materials handling plant to be fully controlled from an operator user interface (i.e. SCADA system interface) or partially controlled from the control desk. The PLC based SCADA system interfaced with the PLC. The process was thus

controlled and monitored by the SCADA system which provided a console for configuration of operating parameters, recipe management, alarm annunciator and data logging.

Drives that were required to be started and stopped during the campaign, e.g. conveyors, feeders etc. were operated by the PLC. Access to this control system was provided through the SCADA system. The drives were, however, equipped with a local console consisting of a manual/automatic change over switch, control potentiometer (where applicable) and start/stop buttons.

The power supply received a power (or current) setpoint whereupon the power supply provided constant power to the furnace (calculated from the current it supplies and the voltage it reads between the anode and cathode) or alternately constant current, depending on the configuration. The power or current setpoints were sourced from the PLC. The voltage setpoint that the operator supplied was used to determine and control the hoist position (i.e. arc length). The power supply used the actual measured voltage between anode and cathode (not the voltage setpoint) to supply constant power.

3.7 Utilities

3.7.1 Cooling water

Cooling water was supplied to the furnace shell and roof, off-gas ducting and power supply (rectifiers, busbars and electrode clamp). The designed maximum flowrate was 134m^3/h. The cooling water was circulated via cooling towers and a reservoir. A header tank on the roof of the pilot plant could supply mains water for emergency cooling.

3.7.2 Propane

A 4,5 ton propane tank and vaporizer capable of delivering 80kg/h at 300 kPa to the pilot plant was available. Small amounts of propane were required for the propane burner heating of the tapping trays.

3.7.3 Oxygen and compressed air

Oxygen used for lancing the furnace tap holes was supplied from a bank of cylinders connected to a manifold. Compressed air, available from the common Mintek supply ($15m^3$/min at 6 bar), was mainly used for pulsing of the bag filters in the gas processing plant and pneumatically activated feed system slide gate valves.

3.7.4 Nitrogen

Nitrogen was required in the pilot plant for purging of the feed system and furnace electrode sealing device. A 3.1 ton nitrogen tank was available capable of providing nitrogen at a flowrate of 180kg/h.

3.7.5 Ancillary power

Apart from the main power supply to the furnace, an additional 138kW of electric power was available to drive ancillary equipment. Bag filter fan Bay 2 (75kW), main cooling water pump (11kW), water pumps at sumps behind the furnace (3kW), screw feeders (total 3kW), small bag filter for dust extraction at feed system (5.5kW), Bay 2 ventilation fans (2 x 15kW) and hydraulics (2 x 1.5kW). Hydraulic power was used for electrode movement.

4 FEED MATERIALS

The type, quality and analysis of the feed materials utilized during the campaign can be seen in Tables 3 and 4.

Table 3 Feed materials utilized in the campaign

Material	Quantity	Supplied by
Slag	57t	Brunswick
Iscor coke	3t	Mintek
Dolomite	550kg	Mintek
Pig iron	500kg	Mintek

As received coke was screened in order to produce material in the size range +2 -10mm.

The slag was supplied with an average particle size of approximately 0,5mm with 16% finer than 0,12mm. This size was reported by Brunswick to be finer than normal due to increased water flowrates during granulation to ensure environmental compliance. The particle size analysis as supplied by Brunswick is shown in Appendix B.

Table 4 Raw material analyses

Slag

Bag No.	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Cr_2O_3 (%)	MnO (%)	FeO (%)	CoO (%)	NiO (%)	CuO (%)	ZnO (%)	PbO (%)
1-4	1.41	3.49	19.9	15.3	0.069	0.45	30.3	<0.06	<0.06	0.36	20.3	3.40
5-8	1.41	3.49	19.8	15.2	0.069	0.45	30.3	<0.06	<0.06	0.37	20.2	3.54
9-12	1.40	3.49	19.8	15.2	0.064	0.45	30.3	<0.06	<0.06	0.37	20.4	3.65
13-16	1.42	3.49	19.8	15.3	0.064	0.45	30.4	<0.06	<0.06	0.37	20.1	3.54
17-20	1.41	3.49	19.8	15.2	0.069	0.45	30.5	<0.06	<0.06	0.38	20.5	3.62
21-24	1.37	3.45	19.6	15.3	0.072	0.44	29.7	<0.06	<0.06	0.37	20.1	4.08
25-28	1.41	3.52	19.8	15.3	0.083	0.45	30.1	<0.06	<0.06	0.37	20.2	3.73
29-32	1.41	3.49	19.7	15.2	0.072	0.45	30.3	<0.06	<0.06	0.37	20.2	3.53
33-37	1.41	3.52	19.9	15.2	0.071	0.45	30.5	<0.06	<0.06	0.37	19.9	3.51
Average	1.404	3.492	19.78	15.24	0.0702	0.449	30.34	<0.06	<0.06	0.369	20.21	3.622

Slag (continued)

Sample	As (%)	Cd (%)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (%)
Average	0.35	0.0042	1.60	0.345	0.400	0.105	0.078	0.097	0.0014

Coke

Sample No.	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	FeO (%)	Ash (%)	C (%)	Vol (%)	H2O (%)	S (%)
1	0.116	3.28	9.89	0.36	1.28	17.7	78.6	2.8	0.9	0.68
2	0.116	3.28	9.89	0.36	1.28	17.5	79.0	3.1	0.3	0.68
Average	0.116	3.28	9.89	0.36	1.28	17.60	78.80	2.95	0.60	0.68

Flux

Sample	CaO (%)	MgO (%)	SiO_2 (%)	LOI (%)
Limestone	50.50	2.28	4.05	38.9
Dolomite	29.45	20.25	1.32	45.1

5 THEORETICAL PREDICTIONS

An equilibrium simulation model was developed using Pyrosim, Mintek's pyrometallurgical simulation software, together with the raw material analyses shown in Table 4. Graphical representations of numerous simulations are shown in Figures 7 and 8 while a sample simulation printout and source data can be seen in Appendix C.

From Figure 7 it can be clearly seen that zinc extraction from the slag is strongly influenced by operating temperature while Figure 8 shows increased alloy or iron production at lower operating temperatures.

6 CAMPAIGN OVERVIEW

The furnace was operated for a period of about 5 days over which 61 batches of lead blast furnace slag and coke were charged to the furnace. Overall 56.7 tonnes of slag was processed, producing approximately 3 tonnes of metal and 44 tonnes of discard slag.

The campaign commenced with a 15 hour warm-up period during which 500kg of pig iron was melted down to form a metal heel. During this period the operating power was incrementally increased from 100 kW to 200 kW. Coke fines (16kg in total) were periodically added to the pig iron to limit oxidation of the metal and refractory attack by FeO. Towards the end of the warm-up the shell and hearth thermocouples indicated temperatures of approximately 800 and 150°C, respectively, while energy losses to the water cooling circuits and atmosphere were measured at 60 kW.

The first smelting recipe (tap) commenced smelting a 1 tonne batch of slag with a 6 per cent coke addition at a power level of 400 kW with energy loss and specific or net energy requirement (SER) setpoints estimated at 150 kW and 0.66 kWh/kg feed, respectively. A temperature of 1421°C was measured for the first tap and it was decided to decrease the SER setpoint to 0.635 kWh/kg feed and temporarily reduce the batch mass to 500kg slag in order to quickly stabilise at the required operating temperature (1350°C).

Figure 7. Theoretical slag analysis vs coke addition

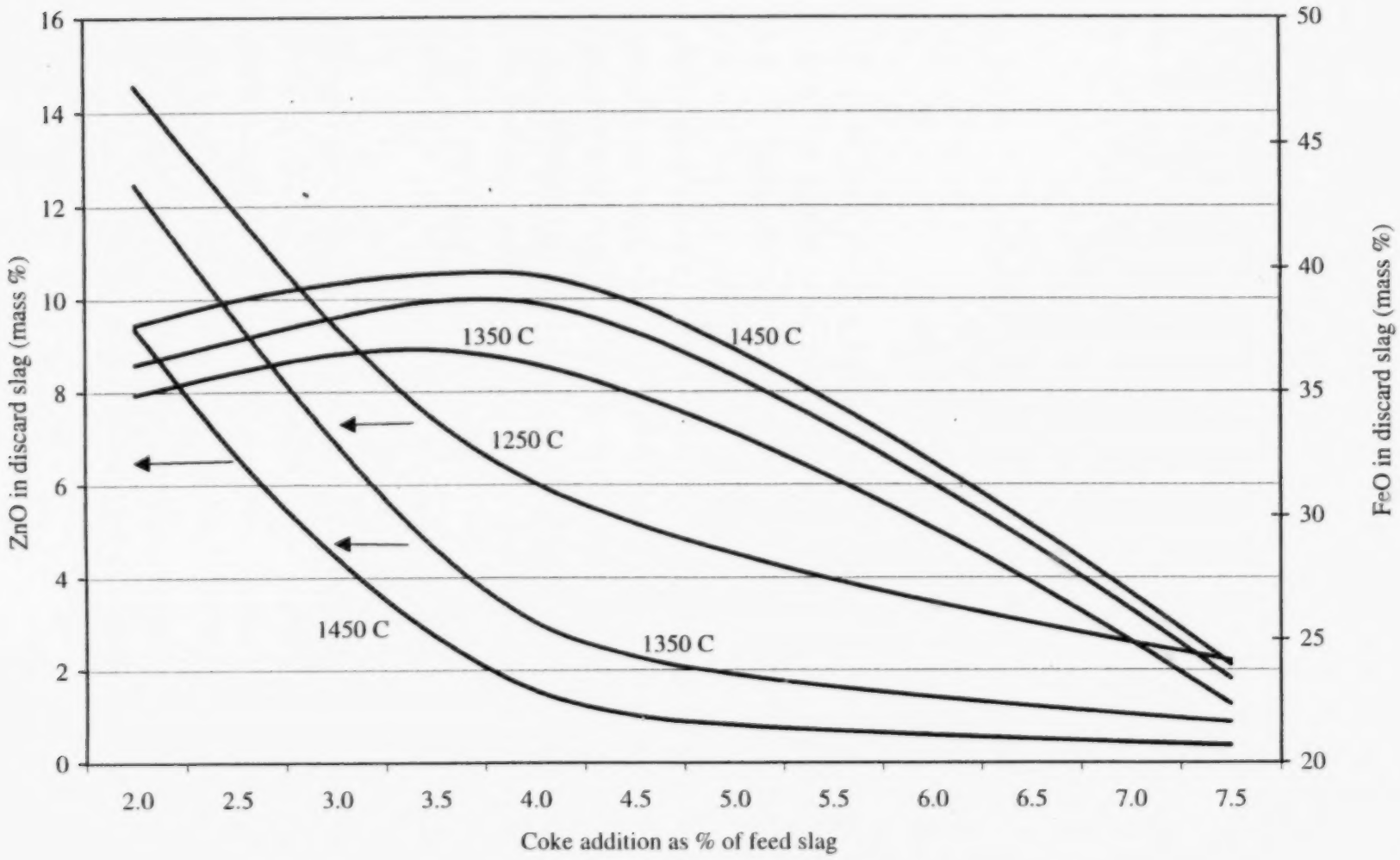
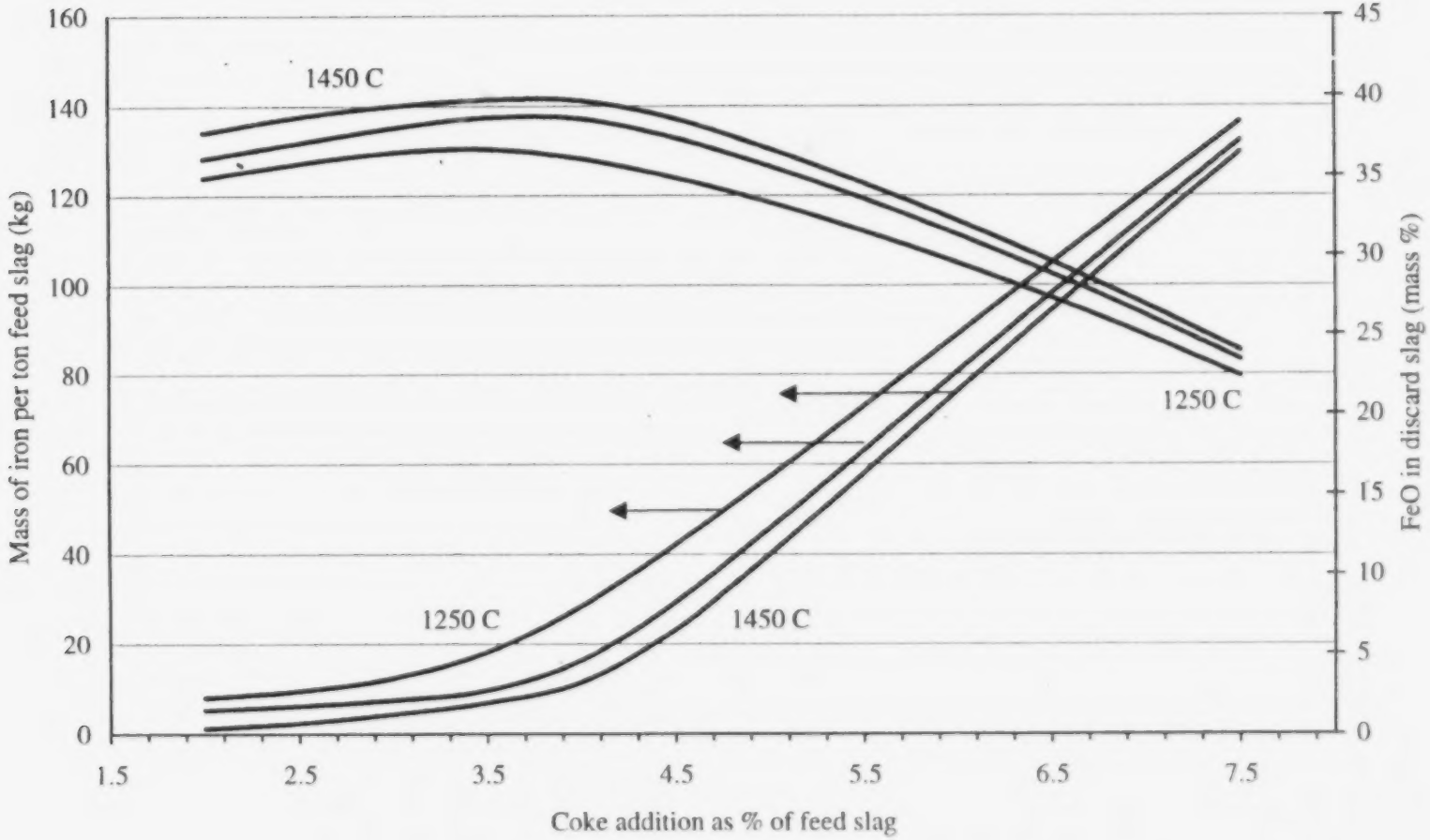


Figure 8. Iron production vs coke addition



Although by tap 3 the temperature had not decreased, it was decided to proceed with the first condition and the operating power was increased to 725 kW with a batch mass of 1000kg slag (6 per cent coke) and energy loss and SER setpoints of 125 kW and 0.635 kWh/kg feed, respectively. The result of these operating parameters was a tapping temperature of 1335°C and slag ZnO content of about 10 per cent.

Over the tap range 4 to 11 the tapping temperature was seen to decrease to around 1200°C in spite of an attempt to increase the available energy to the process. An inspection of the feed system revealed a faulty valve which resulted in more material being fed than was actually measured (overfeeding). The slag discard slag ZnO content was seen to stabilise at around 10 per cent during this period.

For taps 13 through 15 the batch mass was again decreased to 500kg slag in an effort to increase the turn around time and quickly reach the required operating temperature. The coke addition was also decreased to 5 per cent as this was felt to be sufficient.

From tap 16 onwards the batch mass was set back to 1000kg slag and tapping temperatures around 1350°C were achieved for taps 16 and 17 with resulting slag ZnO contents of around 5 per cent.

For similar energy input settings (SER 0.75; 175 kW heat loss) the tapping temperature was seen to rapidly rise to a high of 1543°C over the tap range 18 through 22 with the result that the discard ZnO slag was seen to drop to around 1 per cent. By decreasing the SER from 0.65 to 0.62 kWh/kg feed it was possible to maintain the tapping temperature around 1450°C over the tap range 23 to 28 and thus complete condition 2 (approximately 3 per cent ZnO).

Over the tap range 29 through 35 an attempt was made to stabilise the operation at a temperature of 1350 to 1400°C at 200 V for comparison with earlier operation at 250 V. This proved difficult to achieve and for an almost constant energy input (SER of 0.6 kWh/kg feed, heat losses of 100 kW) the operating temperature was seen to decrease to 1261°C by tap 35.

Tap 36 saw the commencement of condition 4 with increased operating power (1000 kW) and this condition continued through to tap 42 achieving a tapping temperature of around

1350°C. For taps 43 through to 46 it was decided to increase the SER setpoint from 0.6 to 0.7 kWh/kg feed in an attempt to undertake measurements at 1450°C.

For tap 47 it was further decided to increase the operating power to 1500 kW in order to generate a further datum point for zinc fuming rate.

Over the tap range 48 to 53 dolomite was included in the recipe, and the operating power decreased to 725 kW. Here again it proved difficult to maintain an operating temperature of around 1450°C in spite of a significant increase in energy input.

For tap 54 it was decided to abandon dolomite addition in favour of operation at 525 kW (500kg slag batches due to low slag resources) which continued until tap 58.

For tap 59 it was decided to flux the furnace with slag only due to a suspicion that a significant coke build-up was present. This theory continued into tap 60 where 3 per cent coke was added in an effort to stabilise the operation and metallurgy before ending the campaign at low power (tap 61) in an effort to produce a freeze lining for measurement and examination in the digout.

7 RESULTS AND DISCUSSION

The planned testwork programme as detailed in Appendix A, although not strictly adhered to was largely completed (changes were made in consultation with the client). The result is that upon examination of the data produced it was possible to isolate 10 conditions or operating regimes as shown in Table 5.

Table 5 Condition summary

Condition	Power kW	Voltage V	Operating temperature	Coke %	Dolomite
1	725	200	1250	6	No
2	725	250	1350	5	No
3	725	200	1500	5	No
4	725	200	1450	5	No
5	725	200	1350	5	No
6	1000	200	1350	5	No
7	1000	200	1450	5	No
8	1500	200	1450	5	No
9	725	200	1300	5	Yes
10	525	200	1350	6	No

Averaged data for each condition will be presented in the following sections while source data with respect to operating parameters, feed and product masses, product analysis and an accumulative elemental mass balance are presented in Tables D1 to D5 in Appendix D.

7.1 Zinc Extraction

Summaries of the operating conditions, raw materials, feed and resultant slag masses and analysis can be seen in Tables 6, 7 and 8, respectively.

Table 6. Average operating parameters

Condition	Tap Range	Power kW	Voltage V	Batch mass kg	Period(min)			Tot Energy kWh	Losses # kW	SER ! kWh/kg feed	Temp C	Fuming rate*	
					Tap- tap	Feed	Down					Tap period	Feed period
1. 725kW, 200V	5-8,11	725	250	1060	88	71	1	917	118	0.591	1238	56	69
1250 C		*0*	*0*	*0*	*6*	*3*	*1*	*29*	*5*	*0.064*	*12*	*9*	*10*
2. 725kW, 250V	13-17	725	250	738	78	61	0	803	162	0.795	1340	54	72
1350 C		*0*	*0*	*255*	*17*	*21*	*0*	*229*	*9*	*0.068*	*17*	*9*	*6*
3. 725kW, 200V	21,22	725	200	1050	130	80	3	1085	125	0.764	1522	59	93
1500 C		*0*	*0*	*0*	*28*	*4*	*3*	*95*	*2*	*0.021*	*21*	*11*	*1*
4. 725kW, 200V	23-28	725	200	1050	104	70	14	901	112	0.660	1441	70	99
1450 C		*0*	*0*	*0*	*28*	*6*	*21*	*60*	*6*	*0.047*	*23*	*16*	*7*
5. 725kW, 200V	30-33	725	200	1050	72	61	1	751	108	0.585	1386	83	98
1350 C		*0*	*0*	*0*	*3*	*0*	*2*	*16*	*1*	*0.019*	*27*	*3*	*1*
6. 1MW, 200V	36-38,	1000	200	1050	47	44	2	737	108	0.619	1358	121	128
1350 C	40,41	*0*	*0*	*0*	*2*	*1*	*3*	*3*	*4*	*0.007*	*6*	*10*	*6*
7. 1MW, 200V	43-46	1000	200	1050	61	51	3	875	125	0.713	1445	110	126
1450 C		*0*	*0*	*0*	*13*	*3*	*4*	*45*	*7*	*0.028*	*16*	*18*	*5*
8. 1.5MW, 200V	47	1500	200	1050	72	23	0	590	133	0.610	1453	61	192
1450 C			*0*								*0*		
9. 725kW, 200V	49-53	725	200	1138	103	101	1	1184	159	0.748	1300	51	52
1300 C, dol		*0*	*0*	*0*	*13*	*10*	*2*	*120*	*16*	*0.081*	*29*	*8*	*8*
10. 525kW, 200V	56-58	525	200	530	87	72	6	633	159	0.752	1326	38	44
1350 C		*0*	*0*	*4*	*22*	*9*	*8*	*84*	*4*	*0.075*	*20*	*10*	*7*
Overall	1-61	757	209	957	95	69	6	871	130	0.684	1356	64	83
		181	*28*	*214*	*42*	*24*	*17*	*201*	*27*	*0.097*	*77*	*28*	*31*

Note: Upper figure is the mean while lower figure is standard deviation

* Conservative fuming rate (kg Zn/hm^2) based on average final crucible diameter (1.286 m)

! SER (specific energy requirement) is the calculated net energy requirement for the process excluding measured thermal losses

Thermal losses as measured

Table 7. Average raw materials fed

Condition	Tap Range	Slag (kg)	Coke (kg)	Dolomite (kg)	Coke/Slag (%)	Dolomite /slag (%)
1. 725kW, 200V 1250 C	5-8,11	1199.7 *120.5*	70.9 *5.6*		5.91	
2. 725kW, 250V 1350 C	13-17	717.4 *248.3*	37.8 *14.7*		5.26	
3. 725kW, 200V 1500 C	21,22	1008.7 *15.1*	57.9 *0.6*		5.74	
4. 725kW, 200V 1450 C	23-28	1023.5 *37.2*	52.0 *2.7*		5.08	
5. 725kW, 200V 1350 C	30-33	1013.0 *9.9*	50.1 *1.0*		4.94	
6. 1MW, 200V 1350 C	36-38, 40,41	1003.7 *9.3*	49.8 *1.2*		4.96	
7. 1MW, 200V 1450 C	43-46	999.5 *5.8*	50.6 *0.7*		5.06	
8. 1.5MW, 200V 1450 C	47	685.0 *0.0*	20.6 *0.0*		3.01	
9. 725kW, 200V 1300 C, dol	49-53	1075.4 *75.0*	55.9 *3.1*	92.6 *13.8*	5.20	8.60
10. 525kW, 200V 1350 C	56-58	506.4 *11.7*	29.7 *4.6*		5.86	

Note: Upper figure is the mean while lower figure is standard deviation

Table 8. Weighted average slag masses and analyses (continued)

Condition	Tap Range	Mass (kg)	PbO (%)	As (%)	Cd (ppm)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (ppm)	Total (%)
1. 725kW, 200V 1250 C	5-8,11	886 *170*	0.32 *0.04*	<0.008	<5	1.64	0.39	0.4	0.09	0.08	0.008	<2.5	98.6
2. 725kW, 250V 1350 C	13-17	550 *184*	0.14 *0.04*	<0.008	<5	1.40	0.45	0.45	0.07	0.08	0.004	<2.5	98.1
3. 725kW, 200V 1500 C	21,22	493 *199*	0.07 *0.01*	<0.008	<5	1.17	0.46	0.46	0.08	0.09	0.007	<2.5	98.7
4. 725kW, 200V 1450 C	23-28	721 *112*	0.14 *0.05*	<0.008	<5	1.68	0.47	0.45	0.08	0.08	0.006	<2.5	98.4
5. 725kW, 200V 1350 C	30-33	760 *43*	0.32 *0.03*	0.021	<5	1.93	0.41	0.41	0.08	0.08	0.016	<2.5	98.1
6. 1MW, 200V 1350 C	36-38, 40,41	700 *98*	0.37 *0.03*	0.017	<5	1.81	0.44	0.44	0.07	0.07	0.013	<2.5	98.2
7. 1MW, 200V 1450 C	43-46	786 *80*	0.19 *0.04*	<0.008	<5	1.67	0.45	0.46	0.06	0.08	0.006	<2.5	97.7
8. 1.5MW, 200V 1450 C	47	543	0.18										95.1
9. 725kW, 200V 1300 C, dol	49-53	921 *78*	0.23 *0.06*	<0.008	<5	1.88	0.39	0.4	0.08	0.08	0.007	<2.5	98.6
10. 525kW, 200V 1350 C	56-58	369 *42*	0.19 *0.04*	<0.008	<5	1.44	0.49	0.47	0.05	0.08	0.005	<2.5	98.1

Note: Upper figure is the mean while lower figure is standard deviation

Table 8. Weighted average slag masses and analyses

Condition	Tap Range	Mass (kg)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Cr_2O_3 (%)	MnO (%)	FeO (%)	CoO (%)	NiO (%)	CuO (%)	ZnO (%)
1. 725kW, 200V 1250 C	5-8,11	886	1.83	4.67	24.03	19.02	0.11	0.56	32.73	<0.06	<0.06	0.17	12.52
		170	*0.18*	*0.51*	*1.08*	*0.96*	*0.01*	*0.02*	*1.89*			*0.01*	*1.11*
2. 725kW, 250V 1350 C	13-17	550	2.83	7.58	30.06	23.61	0.33	0.66	25.51	<0.06	<0.06	0.12	4.79
		184	*0.17*	*0.47*	*1.13*	*0.99*	*0.08*	*0.02*	*1.04*			*0.02*	*0.88*
3. 725kW, 200V 1500 C	21,22	493	2.88	5.90	30.10	23.07	0.48	0.72	31.94	<0.06	<0.06	0.13	1.12
		199	*0.11*	*0.36*	*0.00*	*0.05*	*0.02*	*0.01*	*0.37*			*0.01*	*0.34*
4. 725kW, 200V 1450 C	23-28	721	2.40	5.49	27.21	20.90	0.31	0.63	35.33	<0.06	<0.06	0.19	3.04
		112	*0.13*	*0.25*	*0.96*	*0.67*	*0.03*	*0.02*	*1.50*			*0.02*	*0.63*
5. 725kW, 20 V 1350 C	30-33	760	1.94	5.02	24.50	19.14	0.21	0.57	37.53	<0.06	<0.06	0.26	5.64
		43	*0.05*	*0.85*	*0.44*	*0.25*	*0.03*	*0.01*	*1.06*			*0.02*	*0.64*
6. 1MW, 200V 1350 C	36-38, 40,41	700	1.74	4.71	25.14	19.74	0.11	0.58	35.56	<0.06	<0.06	0.23	7.11
		98	*0.01*	*0.37*	*0.57*	*0.19*	*0.01*	*0.01*	*0.45*			*0.02*	*0.30*
7. 1MW, 200V 1450 C	43-46	786	1.97	5.11	27.19	20.62	0.18	0.62	35.41	<0.06	<0.06	0.22	3.50
		80	*0.03*	*0.13*	*0.63*	*0.58*	*0.01*	*0.01*	*0.85*			*0.02*	*0.47*
8. 1.5MW, 200V 1450 C	47	543	1.99	4.54	25.70	19.80	0.19	0.60	38.20	<0.06	<0.06	0.27	3.60
9. 725kW, 200V 1300 C, dol	49-53	921	3.45	4.80	24.71	21.51	0.10	0.62	31.80	<0.06	<0.06	0.21	8.31
		78	*0.27*	*0.68*	*0.56*	*0.75*	*0.02*	*0.01*	*0.69*			*0.01*	*1.56*
10. 525kW, 200V 1350 C	56-58	369	2.75	5.73	29.89	23.65	0.17	0.69	27.61	<0.06	<0.06	0.13	4.77
		42	*0.32*	*0.31*	*1.16*	*1.08*	*0.02*	*0.03*	*2.36*			*0.04*	*1.00*

As expected from these tables and the graphical representation in Figure 9 the zinc extraction from the slag is strongly influenced by operating temperature. Operation at 1350°C would result in an residual ZnO content of the slag in the order of 5 per cent while a temperature greater than 1450°C would be required to reduce the discard slag ZnO content to below 3 per cent. This result is in good agreement with that obtained for Doe Run slag (basicity 1)[8] considering the lower basicity ($[MgO + CaO]/SiO_2 = 0.84$) of the slag processed.

A plot of ZnO in the discard slag versus the coke addition is shown in Figure 10. Here no correlation can be made suggesting that excess coke was always present in the furnace for an average campaign addition of 5 per cent. This addition is the same as utilised for the Doe Run testwork and similarly there is scope for optimisation.

The Pyrosim prediction for iron production of the order of 50kg per ton of slag is slightly higher than that achieved for the entire campaign of 31.4kg which is in turn in good agreement with the value of 36.9kg achieved for Doe Run slag. A plot of the slag iron content versus operating temperature is shown in Figure 11.

Figure 9. Discard slag ZnO content vs operating temperature

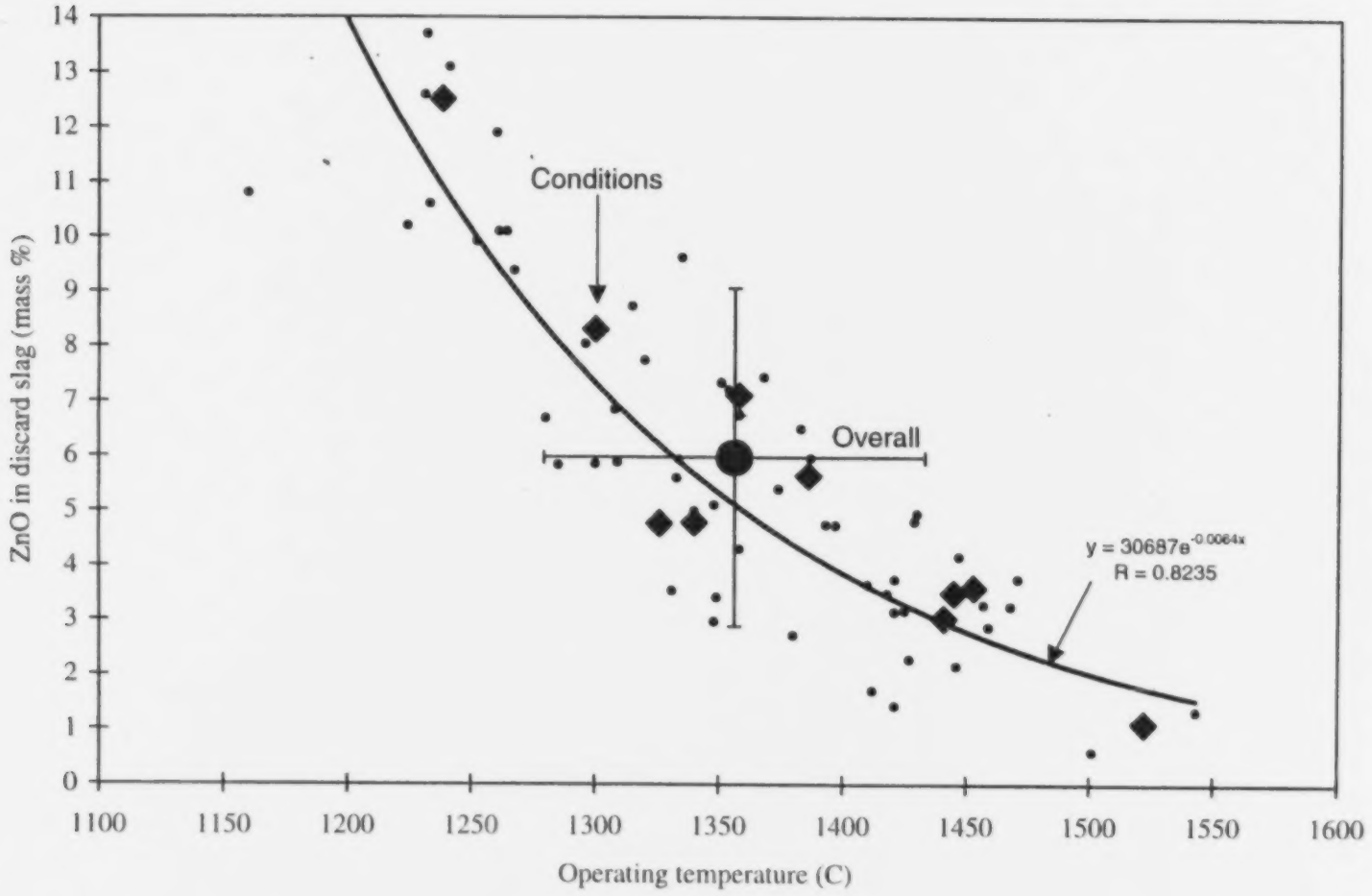


Figure 10. Discard slag ZnO content vs coke addition

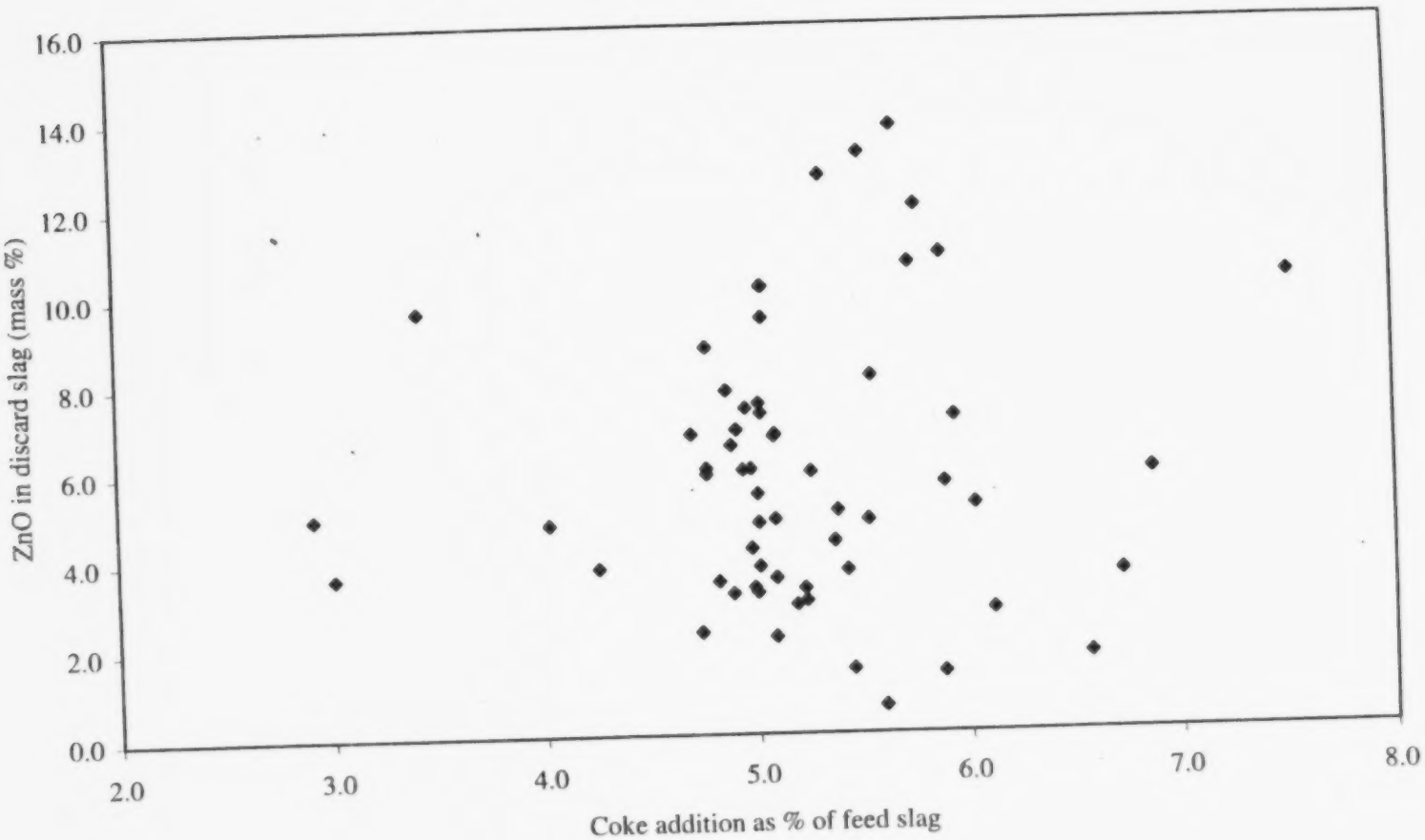
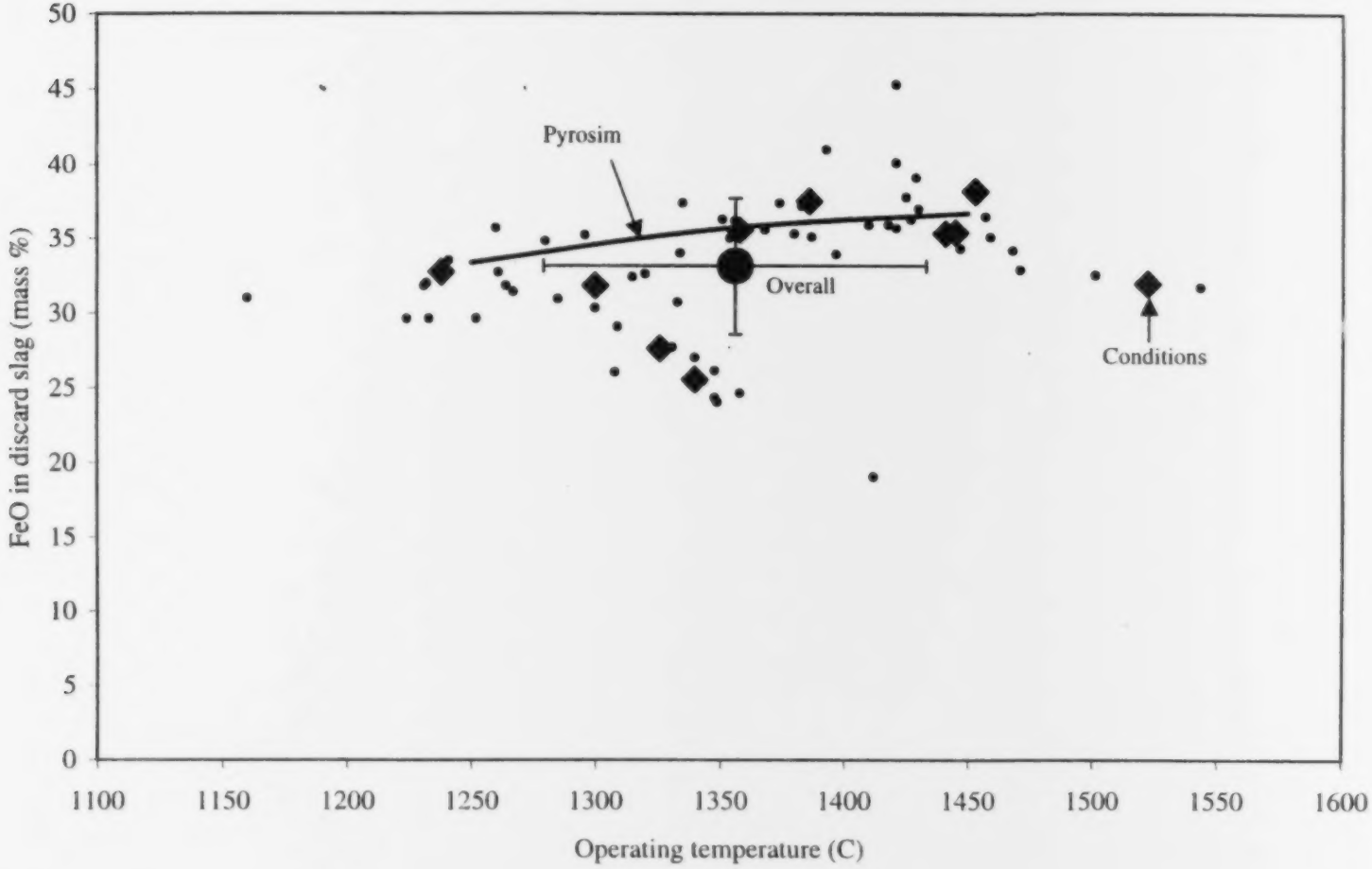


Figure 11. Discard slag FeO content vs operating temperature



7.2 Energy Requirements

Throughout the campaign an attempt was made to balance the feed and energy input in order to achieve a desired tapping or operating temperature. Operating at a constant power level the feedrate was adjusted according to the measured energy losses and estimated reaction energy requirements such that the total energy input and total feed input were balanced at the end of the tap-to-tap period or batch. Graphs of the measured heat losses versus tap number for the various cooling circuits and measured shell temperatures versus time are shown in Figures E1 and E2 in Appendix E, respectively.

A plot of the reaction energy requirements (SER) versus operating temperature is shown in Figure 12. While the individual points show a reasonable variance due to thermal lead and lag of the furnace, values for each condition and for the entire campaign (0.68 MWh/t feed at 1356°C) are in good agreement with the Pyrosim estimation and that achieved with Doe Run slag (0.700 MWh/t feed) albeit at a slightly higher operating temperature (1450°C).

7.3 Fuming Rate

During the furnace digout the average maximum crucible diameter was measured at 1.286m. Utilising this value, a conservative fuming rate for each tap can be calculated based on either the total tap duration or the feed-on period (Table 6). Figure 13 shows a plot of zinc fuming rate versus power density based on the feed-on period. This value is felt to be a more reliable value due to little visible fuming encountered during feed off periods.

From Figure 13 it can be seen that fuming rates of between 44 and 192kg of Zn/hm^2 were achieved for operating powers between 525 and 1500 kW (0.404 and 1.155 MW/m^2), respectively. The linearity of these plots suggests that the fuming rate was directly proportional to the feedrate with no kinetic limitation being encountered at either end of the spectrum.

Figure 12. Energy requirements vs operating temperature

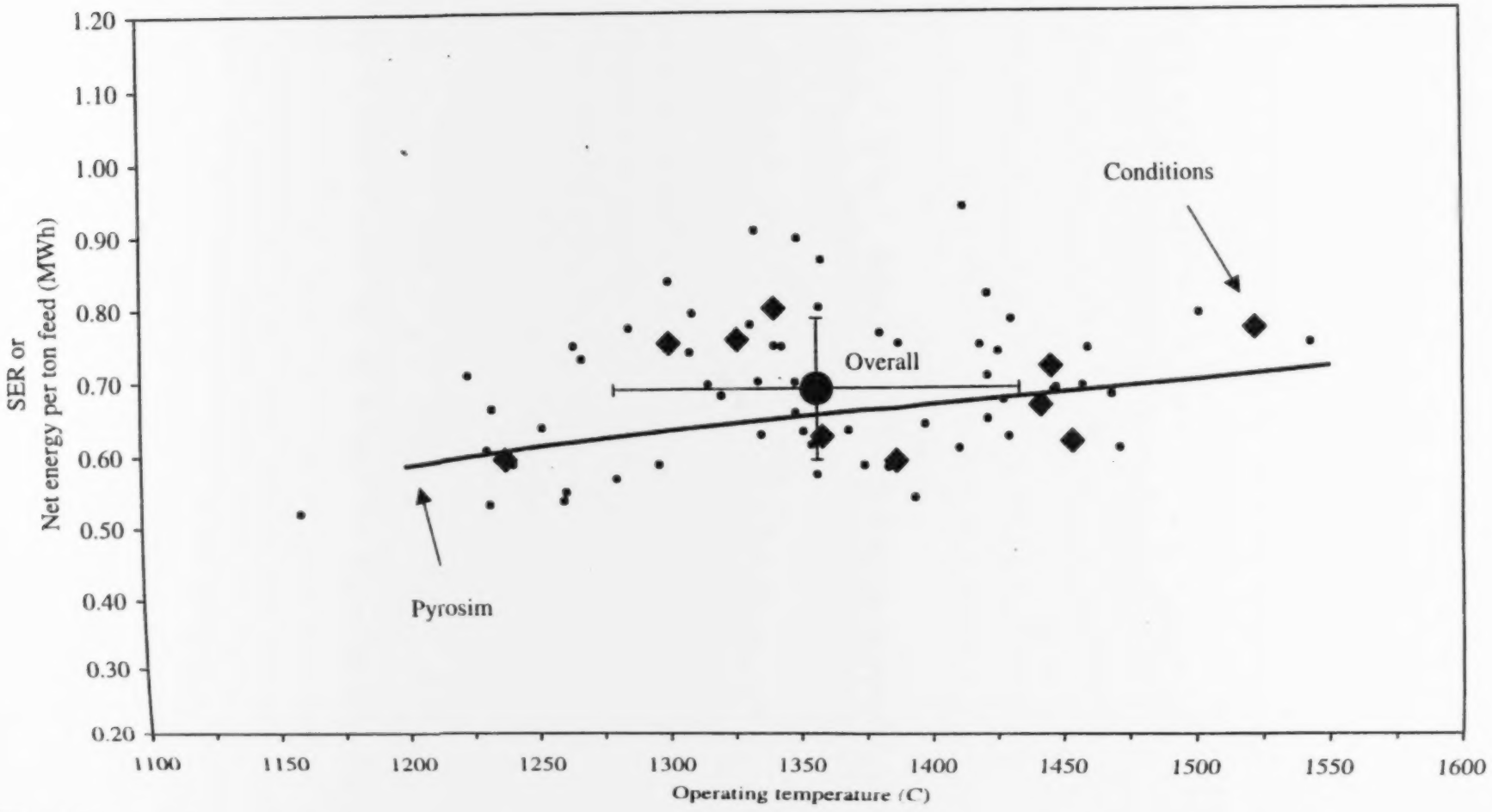
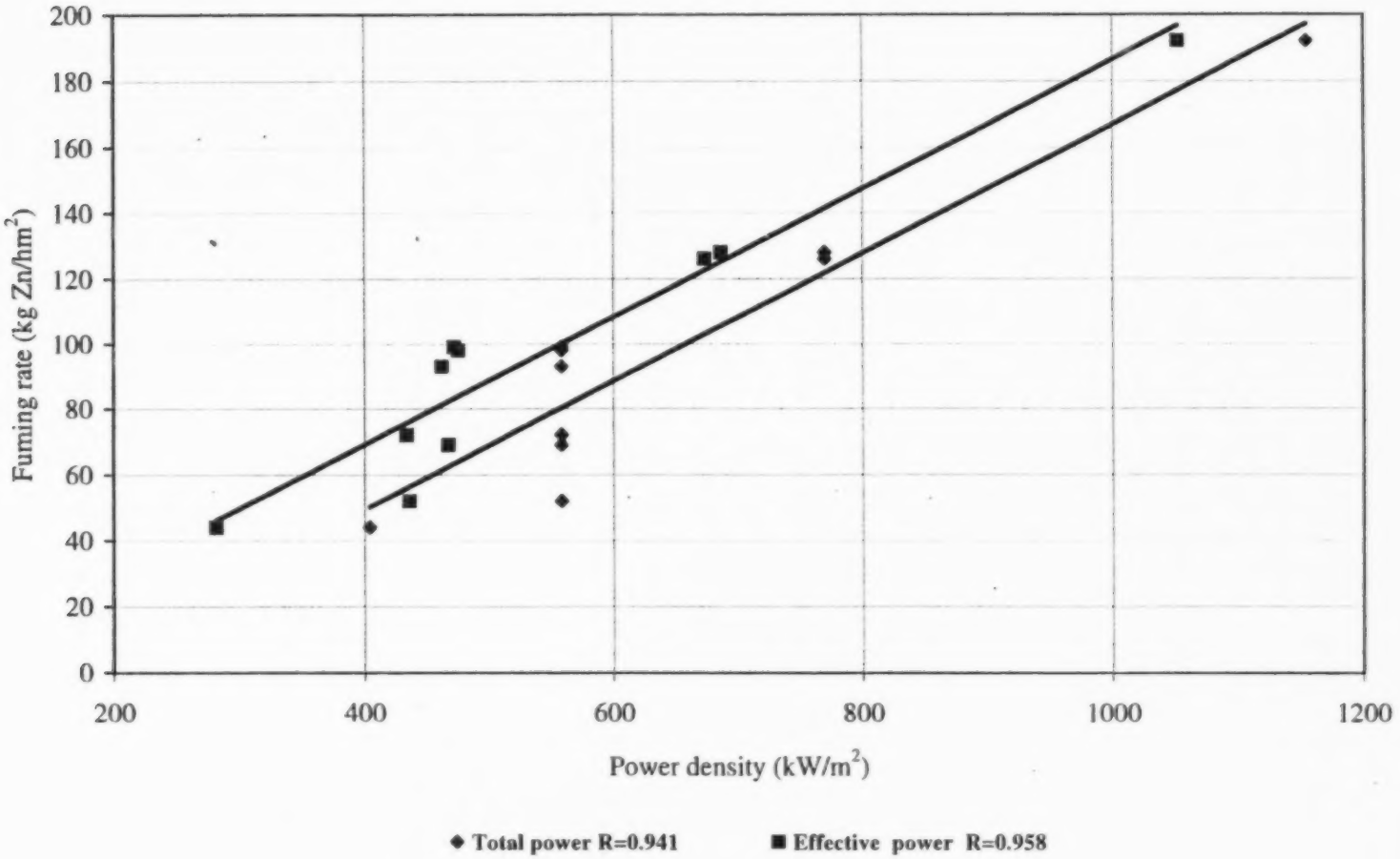


Figure 13. Effect of power density on fuming rate



Comparing conditions 4, 7 and 8 (725, 1000 and 1500 kW) where both current and power density were significantly different no significant effect on the reaction kinetics can be seen. Similarly a comparison between conditions 2 and 5 for repeated operation at 725 kW but differing current densities (2.2 viz. 2.8 kA/m^2) and conditions 5 and 10 for similar current densities but differing power densities, show little difference with regard to zinc extraction. A large difference is however encountered for iron reduction. Although the cause of this observation is uncertain it must be mentioned that energy consumption and iron reduction appeared to be accelerated at lower operating temperatures and shallow molten baths.

7.4 Dolomite Addition

During condition 9 sufficient dolomite was added in order to increase the slag MgO content from around 2 to 3.5 per cent and basicity from 0.84 to 1.01.

Only a limited amount of time was spent on this condition due to its low priority coupled with almost immediate operational difficulties. It became apparent early on that both the energy requirements and reductant addition would need to be increased due to carbonate addition.

Unfortunately the only other result that may be drawn from this condition is that a small MgO addition does not appear to affect zinc fuming kinetics.

7.5 Fume and Dust

Weighted average fume masses and analyses for each condition have been summarised in Table 9. Here it can be seen that for periods of lower operating temperature and where the energy input was increased in order to raise the operating temperature (conditions 1, 2, 9 and 10) increased quantities of Mg, Al, Si and Fe amongst others reported to the off gas. This is probably as a result of elevated arc attachment zone temperatures giving rise to highly reducing conditions.

Table 9. Weighted average fume masses and analyses

Condition	Tap Range	Mass (kg)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Cr_2O_3 (%)	MnO (%)	FeO (%)	CoO (%)	NiO (%)	CuO (%)	ZnO (%)
1. 725kW, 200V	5-8,11	208	0.298	0.596	2.60	1.73	0.012	0.097	3.10	<0.06	<0.06	0.120	67.35
1250 C		*93*	*0.149*	*0.143*	*0.47*	*0.39*	*0.005*	*0.025*	*0.26*			*0.018*	*1.93*
2. 725kW, 250V	13-17	185	0.654	0.754	4.02	2.67	0.048	0.145	4.40	<0.06	<0.06	0.176	66.72
1350 C		*53*	*0.103*	*0.090*	*0.65*	*0.42*	*0.035*	*0.022*	*0.72*			*0.010*	*1.61*
3. 725kW, 200V	21,22	145	0.080	0.075	0.48	0.37	0.007	0.060	0.46	<0.06	<0.06	0.040	78.75
1500 C		*0*	*0.000*	*0.015*	*0.01*	*0.01*	*0.000*	*0.000*	*0.06*			*0.000*	*1.65*
4. 725kW, 200V	23-28	210	0.085	0.111	0.67	0.37	0.007	0.060	0.64	<0.06	<0.06	0.047	79.61
1450 C		*120*	*0.008*	*0.042*	*0.24*	*0.15*	*0.000*	*0.000*	*0.33*			*0.008*	*2.30*
5. 725kW, 200V	30-33	309	0.094	0.223	1.18	0.82	0.007	0.060	1.25	<0.06	<0.06	0.054	74.97
1350 C		*99*	*0.012*	*0.073*	*0.37*	*0.13*	*0.000*	*0.000*	*0.48*			*0.009*	*2.39*
6. 1MW, 200V	36-38,	137	0.080	0.241	0.92	0.68	0.052	0.060	0.93	<0.06	<0.06	0.057	76.64
1350 C	40,41	*0*	*0.000*	*0.114*	*0.20*	*0.43*	*0.032*	*0.000*	*0.40*			*0.018*	*0.70*
7. 1MW, 200V	43-46	178	0.080	0.163	0.83	0.37	0.007	0.060	0.55	<0.06	<0.06	0.040	75.95
1450 C		*39*	*0.000*	*0.024*	*0.05*	*0.04*	*0.000*	*0.000*	*0.14*			*0.000*	*0.76*
8. 1.5MW, 200V	47	156	0.080	0.180	0.87	0.40	0.007	0.060	0.65	<0.06	<0.06	0.040	76.50
1450 C													
9. 725kW, 200V	49-53	284	0.436	0.507	2.55	1.65	0.007	0.072	2.39	<0.06	<0.06	0.118	72.14
1300 C, dol		*77*	*0.082*	*0.047*	*0.31*	*0.32*	*0.000*	*0.008*	*0.38*			*0.021*	*0.57*
10. 525kW, 200V	56-58	105	0.312	0.595	3.06	2.17	0.008	0.091	3.34	<0.06	<0.06	0.101	69.58
1350 C		*10*	*0.122*	*0.258*	*1.19*	*0.96*	*0.000*	*0.020*	*1.31*			*0.023*	*2.63*

Table 9. Weighted average fume masses and analyses (continued)

Condition	Tap Range	Mass (kg)	PbO (%)	As (%)	Cd (%)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (%)	Total (%)
1. 725kW, 200V 1250 C	5-8,11	208 *93*	16.03 *0.88*	0.402	0.108	1.34	0.32	0.72	0.30	0.70	0.162	0.012	96.0
2. 725kW, 250V 1350 C	13-17	185 *53*	13.80 *0.69*	0.344	0.052	1.08	0.30	0.63	0.19	0.17	0.189	0.009	96.3
3. 725kW, 200V 1500 C	21,22	145 *0*	16.05 *0.95*	0.114	0.056	1.05	0.08	0.35	0.25	0.10	0.089	0.010	98.5
4. 725kW, 200V 1450 C	23-28	210 *120*	14.69 *1.17*	0.212	0.058	1.22	0.13	0.42	0.35	0.20	0.105	0.009	99.0
5. 725kW, 200V 1350 C	30-33	309 *99*	15.17 *0.43*	0.120	0.064	1.18	0,11	0.39	0.24	0.16	0.096	0.008	96.2
6. 1MW, 200V 1350 C	36-38, 40,41	137 *0*	15.37 *0.82*	0.262	0.072	1.13	0.09	0.34	0.26	0.12	0.116	0.008	97.4
7. 1MW, 200V 1450 C	43-46	178 *39*	17.69 *1.09*	0.325	0.050	1.28	0.07	0.37	0.22	0.13	0.123	0.010	98.3
8. 1.5MW, 200V 1450 C	47	156	16.90										95.7
9. 725kW, 200V 1300 C, dol	49-53	284 *77*	14.77 *1.17*	0.390	0.069	1.09	0.18	0.55	0.27	0.15	0.127	0.008	97.5
10. 525kW, 200V 1350 C	56-58	105 *10*	15.49 *1.09*	0.264	0.052	1.05	0.17	0.46	0.21	0.12	0.097	0.008	97.2

Note: As in some taps no fume was collected, it has been assumed that fume that was collected can be distributed evenly over the preceeding taps. Upper figure is the mean while lower figure is standard deviation

Taking conditions 3 to 8 to be more representative of stable operation then levels of fume impurities are relatively low. Samples of accretions collected in the off-gas ducting (Table D4, Appendix D) clearly show a degree of feed carry-over. Assuming the elements such as Mg, Ca, Si, Al and Fe are not fumed at all and only report to the off gas as feed carry-over then the feed carry-over is conservatively estimated at around 1 per cent.

Zinc, lead, cadmium and bismuth are seen to report primarily to the fume while elements such as Na, K, Cl, F and S appear to be relatively stable in the slag phase (Table 11).

7.6 Metal

As mentioned in an earlier section the iron production for the entire campaign is calculated at 31.4kg per ton of feed slag. From Table 10 it can be seen that iron accounts for some 80 per cent of the alloy composition with Cu, S, As and Sb making significant contributions. From the elemental mass balance in Table 11 it can be seen that the overall recovery of Cu, S, As and Sb to the metal is calculated at 43, 7, 48 and 52 per cent respectively. While small traces of Co, Ni and V were encountered in the alloy, these elements were not quantitatively analysed in the feed slag and therefore the recovery cannot be reported.

Only 4.6 per cent of the lead input is seen to report to the furnace hearth which amounts to 1.5kg per ton of feed slag.

7.7 Elemental Mass Balance

The overall accountabilities of major slag components as shown in Table 11 are very good. The high accountabilities of Mg, Al and Cr were probably due to some refractory erosion of the furnace sidewalls and roof which amount to a small gain of 72.8; 158 and 37.2kg of these elements respectively.

Table 10. Metal masses and analyses

Tap No.	Mass (kg)	Mg (%)	Al (%)	Si (%)	Ca (%)	Cr (%)	Mn (%)	Fe (%)	Co (%)	Ni (%)	Cu (%)	Zn (%)	Pb (%)	Ti (%)	V (%)	C (%)	As (%)	S (%)	Sb (%)	Bi (ppm)	Total (%)
20	817	0.09	0.50	0.26	<0.05	0.07	<0.05	85.2	0.34	0.05	2.29	0.10	1.25	<0.05	0.06	0.065	3.01	2.68	0.83	5.8	96.7
26	560	<0.05	0.60	0.07	<0.05	<0.05	<0.05	86.5	0.31	0.07	2.13	0.40	0.44	<0.05	<0.05	0.017	2.62	3.20	0.77	4.3	97.1
47	395	<0.05	0.53	0.12	<0.05	<0.05	<0.05	78.9	0.62	0.06	4.11	0.49	0.89	<0.05	0.08	0.038	5.72	3.50	1.73	7.3	96.8
54	*spl*	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	0.49	<0.05	<0.05	3.53	0.33	90.0	<0.05	0.27	0.005	0.19	0.02	2.66	860.0	97.6
61	*spl*	<0.05	0.08	0.10	<0.05	<0.05	<0.05	77.1	0.74	0.09	3.81	0.13	5.44	<0.05	0.06	0.006	8.12	1.85	2.59	77.0	100.1
Digout1	17	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	0.043	<5 ppm	99.6	*n/a*	*n/a*	*n/a*	0.11	*n/a*	0.18	630.0	100.0
Digout2	1028	<0.05	0.23	0.60	<0.05	0.24	<0.05	80.3	0.54	0.05	2.47	1.75	5.38	<0.05	*n/a*	0.080	3.30	1.00	1.05	40.0	97.0
Total/avg	2817	<0.06	0.39	0.23	<0.05	0.16	<0.05	81.58	0.51	0.06	2.96	0.57	2.68	<0.05	<0.06	0.041	4.55	2.45	1.39	26.9	97.6

Note: **Digout1** is lead material collected during the digout
Digout2 is a sample of the metallic heel
spl indicates that only a sample was collected from the tapping tray
avg is the average analysis of taps 20,26,47,61and Digout2
n/a represents not analysed

Table 11. Elemental mass balance

Condition	Tap Range	Stream	Mg (%)	Al (%)	Si (%)	Ca (%)	Cr (%)	Mn (%)	Fe (%)	Cu (%)	Zn (%)	Pb (%)	As (%)	Cd (%)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (%)
1.725kW		Slag	95.7	93.6	87.2	92.1	115.7	92.3	79.7	34.2	45.8	6.50	1.7	8.8	73.9	83.5	73.9	63.3	71.0	5.7	13.2
200V	5-8,11	Metal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1250 C		Fume	4.09	3.18	2.53	2.27	3.09	4.18	2.00	6.33	65.1	84.3	7.7	414.7	14.8	17.6	33.5	48.8	130.8	34.2	152.8
		Total	99.8	96.8	89.7	94.3	118.8	96.5	81.7	40.5	110.8	90.8	9.4	423.5	88.7	101.1	107.4	112.1	201.8	39.9	166.0
2.725kW		Slag	153.4	158.4	113.4	118.5	361.0	113.0	64.4	23.9	18.2	2.9	1.8	9.1	65.6	99.9	86.2	51.1	78.6	3.0	13.7
250V	13-17	Metal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1350 C		Fume	12.0	5.31	5.11	4.51	17.7	8.31	3.75	12.3	85.1	98.2	20.1	326.8	16.9	17.2	35.0	51.2	47.9	42.0	171.4
		Total	165.4	163.7	118.5	123.0	378.7	121.4	68.2	36.1	103.2	101.1	21.9	335.9	82.4	117.2	121.2	102.3	126.5	45.0	185.1
3.725kW		Slag	99.5	78.2	72.2	73.8	330.3	78.0	51.4	17.7	2.71	0.98	1.1	5.8	34.9	65.1	56.1	37.2	56.3	3.5	8.7
200V	21,22	Metal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1500 C		Fume	0.81	0.28	0.34	0.34	1.43	1.92	0.22	1.56	56.0	63.7	4.7	191.7	9.2	3.2	12.6	34.2	18.4	13.2	102.7
		Total	100.3	78.5	72.6	74.2	331.8	79.9	51.6	19.3	58.7	64.7	5.8	197.5	44.1	68.3	68.7	71.4	74.8	16.7	111.4
4.725kW		Slag	119.7	105.6	94.4	96.5	313.8	98.4	82.0	36.2	10.6	2.8	1.6	8.4	72.4	95.9	79.2	53.6	72.2	4.6	12.6
200V	23-28	Metal	0.00	2.83	0.07	0.00	0.00	0.00	33.5	65.80	0.22	1.19	68.27	0.41	17.85	0.00	0.00	0.00	0.00	72.39	2.80
1450 C		Fume	1.2	0.6	0.68	0.49	2.04	2.74	0.43	2.6	80.8	83.2	11.4	288.7	15.2	7.5	21.2	64.3	50.6	21.8	129.1
		Total	120.9	109.0	95.2	96.9	315.9	101.1	115.9	104.6	91.6	87.2	81.3	297.5	105.4	103.4	100.4	118.0	122.8	98.9	144.5
5.725kW		Slag	103.3	103.0	91.2	94.1	220.1	94.7	92.8	52.9	20.9	6.6	4.4	8.9	88.6	89.1	76.8	57.1	76.9	12.4	13.4
200V	30-33	Metal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1350 C		Fume	2.0	1.87	1.77	1.53	3.04	4.08	1.26	4.4	113.3	127.9	10.5	465.2	22.1	9.3	29.4	69.8	62.6	30.2	174.4
		Total	105.3	104.8	93.0	95.6	223.2	98.8	94.0	57.2	134.2	134.4	14.9	474.1	110.6	98.4	106.2	126.9	139.5	42.6	187.8
6. 1MW		Slag	86.1	89.7	87.0	90.2	113.2	90.6	81.7	45.0	24.5	7.0	3.3	8.3	77.0	88.9	76.6	46.5	62.5	9.3	12.4
200V	36-38,	Metal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1450 C		Fume	0.8	0.95	0.65	0.64	10.7	1.92	0.44	2.2	54.5	61.0	10.8	246.3	9.9	3.6	12.2	35.6	22.1	17.2	82.1
	40,41	Total	86.9	90.7	87.6	90.8	123.9	92.6	82.1	47.2	79.0	68.0	14.1	254.6	86.9	92.4	88.9	82.0	84.6	26.5	94.5
7. 1MW		Slag	110.0	109.9	105.4	106.7	198.8	109.0	91.8	45.8	13.6	4.2	1.8	9.4	80.4	102.6	90.4	44.9	80.7	5.1	14.0
200V	43-46	Metal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1350 C		Fume	1.0	0.79	0.73	0.43	1.78	2.38	0.32	1.9	67.0	87.1	18.7	265.3	12.6	7.4	21.8	42.4	32.7	23.1	110.7
		Total	111.0	110.7	106.2	107.1	200.6	111.4	92.1	47.7	80.7	91.3	20.5	274.6	93.0	110.0	112.2	87.3	113.4	28.2	124.7
8.1.5MW		Slag	112.0	99.8	101.5	102.9	214.5	106.0	99.9	57.9	14.1	3.9	2.3	9.4	81.2	98.8	85.2	52.8	81.3	6.5	14.2
200V	47	Metal	0.00	16.1	0.74	0.00	0.00	0.00	193.2	802.9	1.74	15.27	942.4	3.43	124.6	0.00	0.00	0.00	0.00	1028	30.1
1450 C		Fume	1.3	1.14	0.99	0.60	2.27	3.04	0.49	2.5	86.2	106.3	25.4	374.2	15.3	11.9	31.3	57.5	43.8	29.8	130.1
		Total	113.3	117.0	103.2	103.5	216.8	109.0	293.6	863.3	102.1	125.5	970.1	387.0	221.1	110.7	116.5	110.3	125.1	1065	174.4
9.725kW		Slag	93.6	112.4	103.8	103.6	124.7	119.1	89.8	47.9	35.2	5.5	2.0	10.2	98.5	96.8	85.7	65.3	87.9	6.0	15.3
200V	49-53	Metal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1300 C		Fume	4.60	4.30	4.24	3.37	3.20	5.33	2.69	9.31	113.45	127.74	31.58	480.15	21.05	16.40	41.50	74.90	57.24	38.42	183.32
dolomite		Total	98.2	116.7	108.0	106.9	127.9	124.4	92.5	57.2	148.7	133.2	33.5	490.3	119.6	113.2	127.2	140.2	145.1	44.4	198.6
10.725kW		Slag	142.0	113.4	107.1	113.0	175.8	112.5	66.4	28.5	17.2	3.8	1.7	8.7	64.0	103.6	85.7	34.7	74.8	3.6	13.0
200V	56-58	Metal	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1350 C		Fume	4.6	3.35	3.13	2.95	2.28	4.19	2.29	5.7	71.5	88.9	15.2	278.1	13.6	10.3	24.3	43.9	39.0	22.7	123.0
		Total	146.6	116.8	110.2	116.0	178.1	116.7	68.7	34.1	88.7	92.6	16.8	286.7	77.6	113.9	110.0	78.7	113.8	26.3	136.0
	Warm-up	Slag	110.0	110.8	98.5	101.5	220.8	104.8	81.8	40.8	24.0	5.33	2.25	9.1	78.9	95.5	82.5	54.0	77.6	6.4	13.7
Overall	to	Metal	0.13	1.08	0.17	0.00	11.15	0.00	16.7	43.2	0.25	4.64	48.2	0.3	6 89	0.00	0.00	0.0	0.0	52.2	7.8
	Digout	Fume	3.17	2.18	1.98	1.67	4.60	3.72	1.35	5.21	77.8	89.3	13.7	338.9	15 0	10.20	25.6	52.3	57.3	27.1	138.6
		Total	113.3	114.1	100.7	103.1	236.5	108.5	99.9	89.2	102.1	99.3	64.2	348.3	100.8	105.7	108.1	106.3	134.9	85.8	160.1

7.8 Refractory Wear

The furnace lining was examined after completion of the campaign and the extent of refractory erosion was determined. A detailed report of the dig-out findings is given in Appendix F.

In general, the refractory wear was far more moderate than expected. A photograph showing the inside of the furnace at the start of the dig-out can be seen in Figure 14 while a schematic indication of the general extent of the erosion of the refractory lining is shown in Figure 15. None of the thermocouples embedded in the refractory walls (at a depth of 50mm) were lost, and the regions of worst wear were the taphole, observation ports and the wall region at the expected slag level i.e. at approximately 650mm below the top of the furnace shell. The maximum diameter recorded at the expected slag level was 1297mm with the average diameter being 1286mm (original inner diameter was 1242mm).

Although there was no freeze lining visible on the bricks, the dig-out revealed numerous banks in the furnace. These banks were found to consist largely of metal (see dig-out metal analyses in Table 10 for composition) with some slag in the upper portion of the banks. However, it was unusually difficult to obtain a dig-out slag sample (see dig-out slag analysis, Table D3 in Appendix D for composition) because even in the uppermost regions of the banks a large amount of metal was interspersed in the slag. It is assumed that the banks formed during the lower power operations during the last few taps (Taps 54-58 and 61). The banks may have decreased the average bath diameter to 1207mm (at a depth of 650mm below the top of the furnace shell) during this period.

Unreacted/partially reacted coke was found in the furnace at the start of the dig-out. The total mass of the loose coke that was removed from the furnace was 63kg and the analysis can be found in Appendix D.

Quantities of lead were found between and behind the bricks and in the Ankerhearth in the hearth of the furnace. The total mass of the lead recovered during the dig-out was 14.217kg. The exact mass of lead removed from each region of the furnace is given in Appendix F. This information may hopefully aid in shedding some light on regions of maximum lead

build-up to facilitate accurate lead drainage in continuous operations. Most of the lead recovered during the dig-out had an iridescent surface coating that was found to be antimony.

Finally, no significant erosion of either the conical or the flat roof refractories (a 95% alumina castable) was evident.

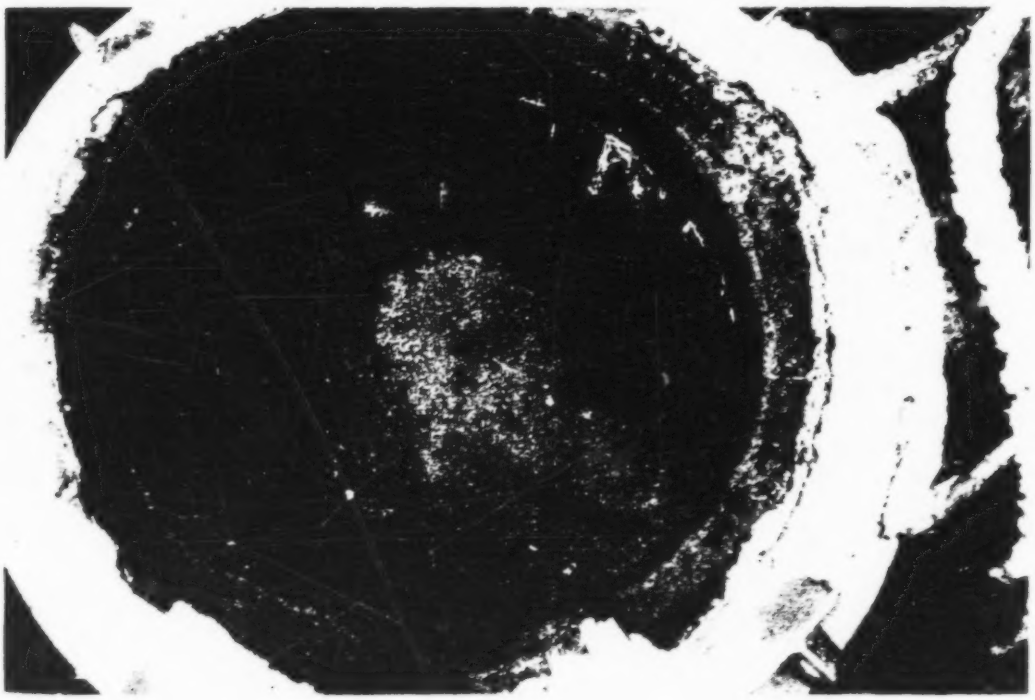
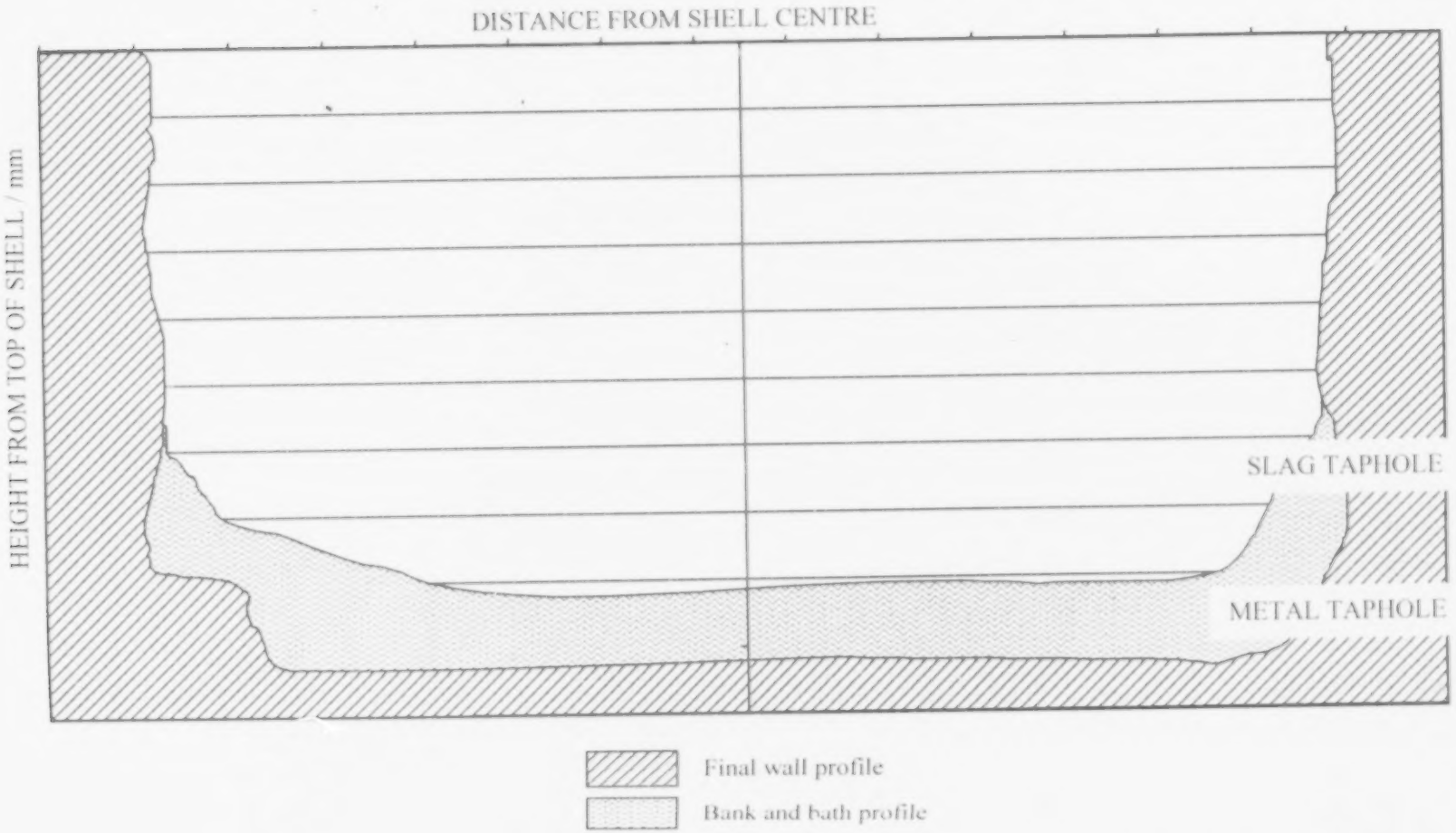


Figure 14. Photograph of the interior of the furnace shell at the start of the furnace dig-out

Figure 15: Typical schematic cross section through the furnace at the end of the campaign



8 CONCLUSIONS

1. For similar operating parameters the chemical behaviour of Brunswick and Doe Run LBFS (with basicity corrections) is directly comparable i.e. the degree of zinc extraction is primarily dependent on the operating temperature.

2. An operating temperature in excess of 1450°C and a coke addition of approximately 5 per cent is required in order to produce a discard slag containing 3 per cent or less zinc oxide.

3. A net energy requirement similar to that achieved for Doe Run of 0.7 MWh/t feed was measured.

4. Neither an increase in the power nor current density produced any apparent effect on the reaction kinetics at this scale of operation.

5. Zinc fuming rates as high as 192kg Zn/hm^2 were achieved together with acceptable overall zinc extraction.

6. Very little information can be drawn from the limited amount of work done with dolomite addition, except that MgO does not appear to adversely affect the ZnO versus temperature relationship.

7. The purity of zinc and lead oxide fume produced was high and the percentage of feed reporting directly to the fume is conservatively estimated at approximately 1 per cent.

8. The overall iron production for the campaign was calculated at 31kg per ton feed slag, which accounts for approximately 80 per cent of the alloy composition. Other major components include Cu, S, As and Sb.

9. The overall deportment of lead to the furnace hearth was calculated at 4.6 per cent of input or 1.5kg per ton of feed slag.

10. The accountability of the major elements in the feed (Fe, Si & Zn) is very good.

11. The furnace sidewall refractories were seen to perform well, with only moderate erosion, although no protective slag freeze lining was encountered.

9 RECOMMENDATIONS

It is recommended that the process be scaled up to the 5.6 MVA pilot plant, so that combined operation with an ISP lead splash condenser can be evaluated and operating data such as energy requirements, reductant addition, tapping temperature, arc characteristics and elemental deportment may be further defined.

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11 APPENDIX A : Brunswick DC-arc Furnace Testwork

APPENDIX A

BRUNSWICK DC ARC FURNACE TESTWORK

	Key paramaters	Condition
Furnace warm-up 600kg/h LBFS solid feed 6% coke 725 kW, 250 V, 2.9 kA Temperature 1350°C Fuming rate >70kg/hm2 2.40 kA/m2, 0.60 MW/m2	1. Setup + Warm-up 2. Effect of temperature on: Zn extraction Alloy production 1-3 days 10 taps 10t LBFS US$ 70 000	1
600kg/h LBFS solid feed 7.5% coke 725 kW, 250 V, 2.9 kA Temperature 1450°C Fuming rate >70kg/hm2 2.40 kA/m2, 0.60 MW/m2	1. Comparison with DoeRun 1 day 10 taps 10t LBFS US$ 18 000	2
600kg/h LBFS solid feed 7.5% coke 725 kW, 190 V, 3.82 kA Temperature 1350 or 1450°C Fuming rate >70kg/hm2 3.16 kA/m2, 0.60 MW/m2	1. Fuming rate vs current density 1 day 10 taps 10t LBFS US$ 18 000	3
960kg/h LBFS solid feed 7.5% coke 1000 kW, 260 V, 3.85 kA Temperature 1350 or 1450°C Fuming rate >100kg/hm2 3.18 kA/m2, 0.83 MW/m2	1. Fuming rate vs power density 1 day 10 taps 10t LBFS US$ 18 000	4
600kg/h LBFS solid feed **X % Dolomite addition*** 7.5% coke 725 kW, 250 V, 2.9 kA Temperature 1350 or 1450°C Fuming rate >70kg/hm2 2.40 kA/m2, 0.60 MW/m2	1. Effect of increased liquidus on: Zn extraction Refractory wear *** Brunswick to advise** 1 day 10 taps 10t LBFS US$ 18 000	5
CONTINGENCY		

12 APPENDIX B – High Grade Zn Slag Size Analysis

Apendix B

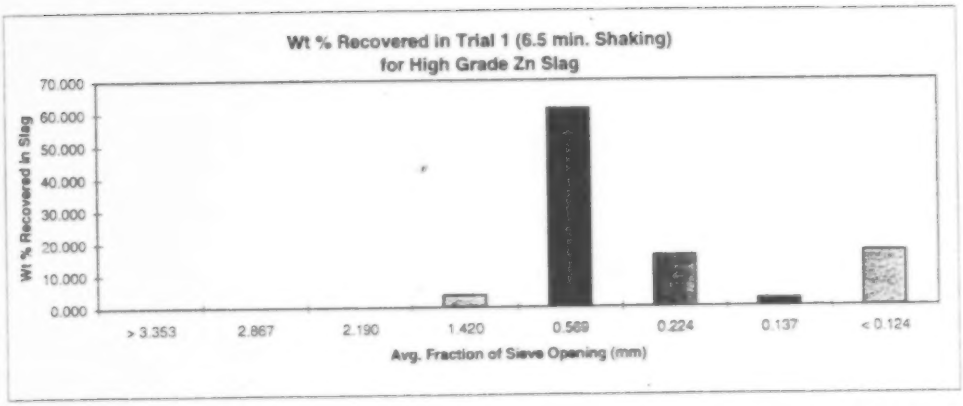
High Grade Zn Slag Size Analysis

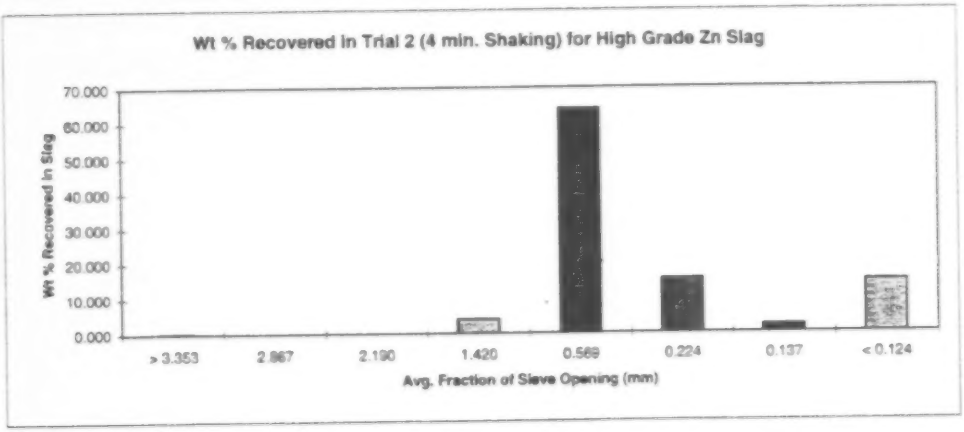
Trial 1: 6.5 min in Shaker

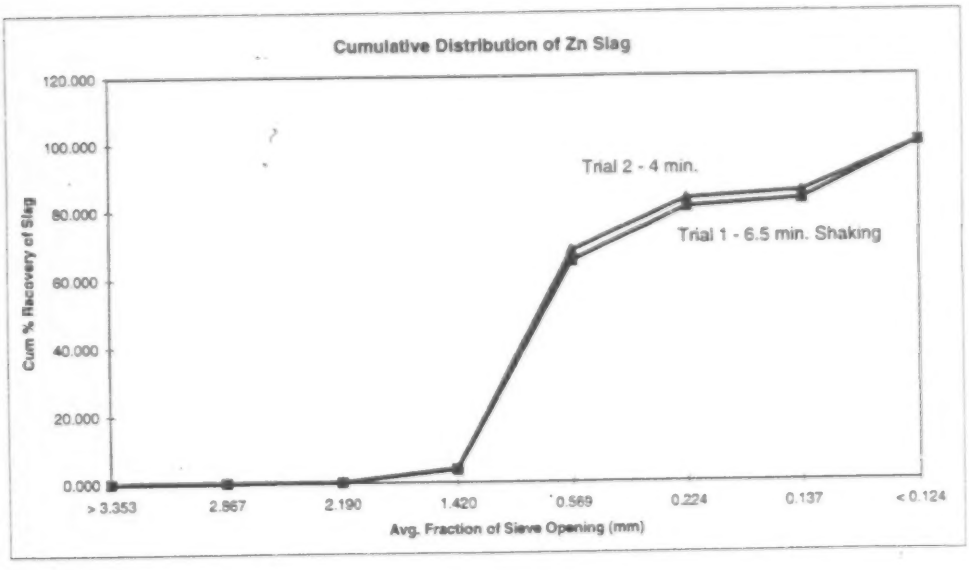
Sieve Opening			Weight of Slag	% Wt Recovered	Cumulative. Wt % Recovered
Inches	Millimeters	Avg. Fraction (mm)	Grams		
> 0.132	> 3.353	> 3.353	0.08	0.013	0.013
0.0937	2.380	2.867	0.13	0.022	0.035
0.0787	1.999	2.190	0.18	0.030	0.065
0.0331	0.841	1.420	22.25	3.716	3.78
0.0117	0.297	0.569	366.78	61.261	65.04
0.0059	0.150	0.224	94.42	15.770	80.81
0.0049	0.124	0.137	13.57	2.267	83.08
< 0.0049	< 0.124	< 0.124	101.31	16.921	100.00
	Total (grams)		**598.72**	**100.00**	

Trial 2: 4 min in Shaker

Sieve Opening			Weight of Slag	% Wt Recovered	Cumulative. Wt % Recovered
Inches	Millimeters	Avg. Fraction (mm)	Grams		
> 0.132	> 3.353	> 3.353	0.64	0.128	0.128
0.0937	2.380	2.867	0.02	0.004	0.132
0.0787	1.999	2.190	0.05	0.010	0.142
0.0331	0.841	1.420	19.64	3.934	4.08
0.0117	0.297	0.569	319.51	64.007	68.08
0.0059	0.150	0.224	75.91	15.207	83.29
0.0049	0.124	0.137	10.37	2.077	85.37
< 0.0049	< 0.124	< 0.124	73.04	14.632	100.00
	Total (grams)		**499.18**	**100.00**	


Wt % Recovered in Trial 1 (6.5 min. Shaking)
for High Grade Zn Slag
Wt % Recovered in Slag
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
> 3.353
2.867
2.190
1.420
0.569
0.224
0.137
< 0.124
Avg. Fraction of Sieve Opening (mm)

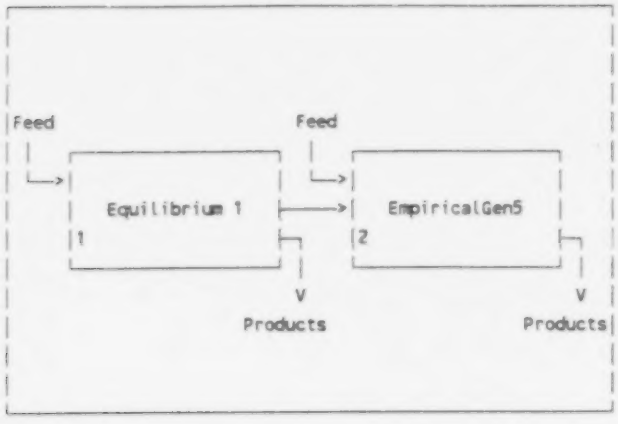

Wt % Recovered in Trial 2 (4 min. Shaking) for High Grade Zn Slag
Wt % Recovered in Slag
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
> 3.353
2.867
2.190
1.420
0.569
0.224
0.137
< 0.124
Avg. Fraction of Sieve Opening (mm)


Cumulative Distribution of Zn Slag
Cum % Recovery of Slag
120.000
100.000
80.000
60.000
40.000
20.000
0.000
Trial 2 - 4 min.
Trial 1 - 6.5 min. Shaking
> 3.353
2.867
2.190
1.420
0.569
0.224
0.137
< 0.124
Avg. Fraction of Sieve Opening (mm)

13 APPENDIX C – Theoretical Predictions

Appendix C

Zinc fuming of Brunswick slag (1450 C, 5% coke)



FLOWRATES

	FLOWRATE (kg/h)	TEMPERATURE (°C)
FEED 1		
Iscor coke	50.000	25
Brunswick	1000.000	25
PRODUCTS 1		
Gas	295.569	1450
Metal	46.540	1450
TO NEXT UNIT		
Slag	685.862	1450
FEED 2		
Nitrogen	0.010	1450
PRODUCTS 2		
Gas	0.012	1450
Slag	685.881	1450

OPERATION

UNIT 1

Equilibrium model calculates multi-phase multi-reaction equilibrium

ELEMENTS: Ag Ar As O S Cl C F H Pb Si Zn Al Ca Fe Mg Cd Co Cr Cu K Mn Na Ni Sb

Gas: Ag(g) Ar As(g) As4O6 AsS(g) Cl2 CO CO2 F2 H2 H2O(g) H2S O2 Pb(g) PbS(g) S2 SiO SO SO2 SO3 Zn(g)

Slag: Ag2O Al2O3(l) Al2Si2O7 Al2SiO5 Al6Si2O13 As2O5 Ca2Fe2O5 Ca2SiO4 Ca3Al2O6 Ca3As2O8 Ca3Si2O7 Ca3SiO5 CaAl2O4 CaAl2SiO6 CaAl4O7 CaF2 CaFe2O4 CaMgO2 CaMgSi2O6 CaMgSiO4 CaO(l) CaS CaSiO3 CdO CdSiO3 Co2SiO4 CoAl2O4 CoFe2O4 CoO Cr2O3 CrO(l) Cu2Fe2O4 Cu2O CuFe2O4 CuO Fe2SiO4 FeAl2O4 FeCr2O4 FeO FeSiO3 K2O K2Si2O5 K2Si4O9 K2SiO3 Mg2SiO4 MgAl2O4 MgCr2O4 MgFe2O4 MgO(l) MgSiO3 MnO MnSiO3 Na2O Na2Si2O5 Na2SiO3 Na4SiO4 Na6Si2O7 Ni2SiO4 NiFe2O4 NiO Pb2SiO4 Pb4SiO6 PbO PbSiO3 Sb2O3 SiO2(l) Zn2SiO4 ZnFe2O4 ZnO ZnSiO3

Metal: Ag As C Cd Co Cr Cu Fe Fe2As Fe3C Fe3Si Fe3Si7 FeSi FeSi2 Mn Ni S Si

Operating temperature = 1450°C
Operating pressure = 1.00 atm

Slag : Metal ratio = 14.74

General Empirical model allows the user to specify ratios and percentages in streams

ELEMENTS: N O Al Ca F S Cd Cr Cu Fe K Hg Mn Na Pb Sb Si Zn

Gas: N2 O2

Slag: Al2O3(l) CaF2 CaO(l) CaS CdO Cr2O3 CuO FeO K2O MgO(l) MnO NZ Na2O PbO Sb2O3 SiO2(l) ZnO

N2 in Gas / N2 in Slag (molar ratio) = 100

Operating temperature = 1450°C

Operating pressure = 1.00 atm

Dust loss = 0%

ENERGY

UNIT 1 requires 577 kWh (2080 MJ) per hour of operation, including a rate of energy loss of 0 kW
This is 12.4 MWh per ton of Metal produced in this unit

UNIT 2 requires 134 kWh (483 MJ) per hour of operation, including a rate of energy loss of 0 kW

ANALYSES
(MASS %)

	Ag	Ag(g)	Ag2O	Ag2S	Al2O3	Al2O3(l)	Al2Si2O7	Al2SiO5	Al6Si2O1	Ar	As
FEED 1											
Iscor coke	.....	.....	.....	.....	3.280	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	3.492	.....	.....	.....	.....	.....	0.350
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.001
TO NEXT UNIT											
Slag	.....	.....	.....	.....	.....	0.352	.....	0.797	0.001	.....	.....
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	5.330	.....	.....	.....	.....	.....

	As(g)	As2O3(a)	As2O3(c)	As2O5	As4O6	AsS(g)	C	C2H2	C2H4	Ca2Fe2O5	Ca2SiO4
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	78.800	.....	2.950	.....	.....
Brunswick	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	0.001	.....	.....	.....	.....	0.002	.....	.....	.....	.....	.....
Gas	0.001	.....	.....	.....	.....	0.004	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	0.017	.....	.....	.....	.....
TO NEXT UNIT											
Slag	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.000	5.090
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

	Ca3Al2O6	Ca3As2O8	Ca3Si2O7	Ca3SiO5	CaAl2O4	CaAl2SiO6	CaAl4O7	CaF2	CaFe2O4	CaMgO2	Ca
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
TO NEXT UNIT											
Slag	0.000	.....	2.002	0.016	0.428	1.386	0.048	0.234	0.004	0.006	2.27
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	.....	.....	0.234	.....	.....	.....

	CaMgSiO4	CaO	CaO(l)	CaS	CaSiO3	Cd	CdAl2O4	CdO	CdS(g)	CdSiO3	Cl
FEED 1											
Iscor coke	.....	0.360	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	15.240	.....	.....	.....	0.013	.....	.....	.....	.....	0.105
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	0.279	.....	.....	.....	.....	.....
TO NEXT UNIT											
Slag	3.253	.....	0.025	3.965	25.271	.....	.....	0.000	.....	.....	.....
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	18.995	3.965	.....	.....	.....	0.000	.....	.....	.....

	Cl2	Cl[-]	Co	CO	CO2	Co2SiO4	CoAl2O4	CoFe2O4	CoO	CoS	Cr
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	0.243	.....	.....	51.980	3.449	.....	.....	.....	.....	.....	.....
Gas	0.355	.....	.....	30.076	3.135	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
TO NEXT UNIT											0.004
Slag	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

	Cr2O3	CrO	CrO(l)	CrO2	CrO3	Cu	Cu2Fe2O4	Cu2O	Cu2S	Cu3As	Cu5FeS4
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	0.070	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	6.332	.....	.....	.....	.....	.....
TO NEXT UNIT											

Slag	0.040	.....	.....	.....	.....						
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	0.102	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

	CuFe2O4	CuFeS2	CuO	CuS	F	F2	Fe	Fe2As	Fe2O3	Fe2SiO4	Fe3C
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	1.420	.....	.....
Brunswick	.....	.....	0.369	.....	0.078	.....	.....	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	74.373	18.666	.....	.....	0.325
TO NEXT UNIT											
Slag	.....	.....	0.000	.....	.....	.....	.....	.....	.....	0.804	.....
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	0.000	.....	.....	.....	.....	.....	.....	.....	.....

	Fe3O4	Fe3Si	Fe3Si7	FeAl2O4	FeAsS	FeCr2O4	FeO	FeS	FeSi	FeSi2	FeSiO3
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	.....	.....	30.270	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	0.000	.....	.....	.....	.....	.....	.....	0.000	.....	.....
TO NEXT UNIT											
Slag	.....	.....	.....	5.215	.....	0.034	33.931	.....	.....	.....	0.121
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	.....	36.732	.....	.....	.....	.....

	H2	H2O	H2O(g)	H2S	HCl	HF	K	K2O	K2Si2O5	K2Si4O9	K2SiO3
FEED 1											
Iscor coke	.....	0.600	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	.....	.....	0.400	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	1.530	.....	0.389	0.075	.....	.....	.....	.....	.....	.....	.....
Gas	0.064	.....	0.145	0.053	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
TO NEXT UNIT											
Slag	.....	.....	.....	.....	.....	.....	.....	.....	1.278	0.157	0.159
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	.....	.....	0.703	.....	.....	.....

	Mg2SiO4	MgAl2O4	MgCr2O4	MgFe2O4	MgO	MgO(l)	MgSiO3	Mn	Mn(l)	MnO	MnSiO3

FEED 1											
Iscor coke	.....	.....	.....	.....	0.116	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	1.404	.....	.....	.....	.....	0.449	.....
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	0.001	.....	.....	.....
TO NEXT UNIT											
Slag	0.144	0.636	0.049	0.000	.....	0.045	1.183	.....	.....	0.319	0.620
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	2.055	.....	.....	.....	0.655	.....

	N2	Na	Na2O	Na2Si2O5	Na2SiO3	Na4SiO4	Na6Si2O7	NaAlO2	Ni	Ni2SiO4	NiFe2O4
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	0.345	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
TO NEXT UNIT											
Slag	.....	.....	0.000	0.999	0.666	0.000	.....	.....	.....	.....	.....
FEED 2											
Nitrogen	100.000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	84.154	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	82.297	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	0.000	.....	0.678	.....	.....	.....	.....	.....	.....	.....	.....

	NiO	NO2	O	O2	Pb	Pb(g)	Pb2SiO4	Pb3O4	Pb4SiO6	PbO	PbS
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.622	.....
PRODUCTS 1											
Gas(vol %)	.....	.....	.....	.....	.....	0.809	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	3.461	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
TO NEXT UNIT											
Slag	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.003	.....
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	15.846	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	17.703	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.007	.....

	PbS(g)	PbSiO3	S	S2	Sb	Sb2O3	Si	SiO	SiO2	SiO2(l)	SO
FEED 1											
Iscor coke	.....	.....	0.680	.....	.....	.....	.....	.....	9.890	.....	.....
Brunswick	.....	.....	1.600	.....	0.097	.....	.....	.....	19.780	.....	.....
PRODUCTS 1											
Gas(vol %)	1.846	.....	.....	0.123	.....	.....	.....	0.000	.....	.....	0.002
Gas	9.123	.....	.....	0.163	.....	.....	.....	0.000	.....	.....	0.002
Metal	.....	.....	0.001	.....	.....	.....	.....	.....	.....	.....	.....
TO NEXT UNIT											
Slag	.....	0.005	.....	.....	.....	0.169	.....	.....	.....	7.448	.....
FEED 2											

Nitrogen	.....	.....	.....	.....							
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	0.169	.....	.....	.....	29.560	.....

	SO2	SO3	Zn	Zn(g)	Zn2SiO4	ZnFe2O4	ZnO	ZnS	ZnSiO3	CaCO3	MgCO3
FEED 1											
Iscor coke	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Brunswick	.....	.....	.....	.....	.....	.....	20.210	.....	.....	.....	.....
PRODUCTS 1											
Gas(vol %)	0.002	.....	.....	39.550	.....	.....	.....	.....	.....	.....	.....
Gas	0.002	.....	.....	53.415	.....	.....	.....	.....	.....	.....	.....
Metal	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
TO NEXT UNIT											
Slag	.....	.....	.....	.....	0.024	0.000	0.787	.....	0.016	.....	.....
FEED 2											
Nitrogen	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas(vol %)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	.....	.....	.....	.....	.....	0.814	.....	.....	.....	.....

ELEMENTAL ANALYSES

(MASS %) Slag constituents are shown as oxides; all others as elements

	Ag	Al/Al2O3	Ar	As	C	Ca/CaO	Cd	Cl	Co	Cr/Cr2O3	Cu
PRODUCTS 1											
Gas	.....	.....	.....	0.004	13.753	.....	.....	0.355	.....	.....	.....
Slag	.....	5.331	.....	.....	.....	22.246	0.000	.....	.....	0.102	0.000
Metal	.....	.....	.....	7.495	0.039	.....	0.279	.....	.....	0.004	6.332
PRODUCTS 2											
Gas	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Slag	.....	5.331	.....	.....	.....	22.246	0.000	.....	.....	0.102	0.000

	F	Fe/FeO	H	K/K2O	Mg/MgO	Mn/Mn2O3	N	Na/Na2O	Ni	O	Pb
PRODUCTS 1											
Gas	.....	.....	0.083	.....	.....	.....	.....	.....	.....	19.590	11.361
Slag	0.114	36.732	.....	0.703	2.056	0.728	.....	0.678	.....	33.330	0.006
Metal	.....	85.849	.....	.....	.....	0.001	.....	.....	.....	.....	.....
PRODUCTS 2											
Gas	.....	.....	.....	.....	.....	.....	82.299	.....	.....	17.701	.....
Slag	0.114	36.732	.....	0.703	2.056	0.728	0.000	0.678	.....	33.330	0.006

	S	Sb	Si/SiO2	Zn/ZnO	e
PRODUCTS 1					
Gas	1.439	.....	0.000	53.415	.....
Slag	1.762	0.141	29.559	0.814	.....
Metal	0.001	.....	0.000	.....	.....
PRODUCTS 2					
Gas	.....	.....	.....	.....	.....
Slag	1.762	0.141	29.559	0.814	.....

DISTRIBUTION OF ELEMENTS

PRODUCTS 1	Gas	Dust	Solids	Slag	Metal	Matte
Al:	.....	.....	.....	100.000%	.....	.....

As:	0.340%	.....	.....	.....	99.660%	.....
C :	99.955%	.....	.....	.....	0.045%	.....
Ca:	.....	.....	.....	100.000%	.....	.....
Cd:	.....	.....	.....	0.031%	99.969%	.....
Cl:	100.000%	.....	.....	.....	.....	.....
Cr:	.....	.....	.....	99.605%	0.395%	.....
Cu:	.....	.....	.....	0.035%	99.965%	.....
F :	.....	.....	.....	100.000%	.....	.....
Fe:	.....	.....	.....	83.055%	16.945%	.....
H :	100.000%	.....	.....	.....	.....	.....
K :	.....	.....	.....	100.000%	.....	.....
Mg:	.....	.....	.....	100.000%	.....	.....
Mn:	.....	.....	.....	99.986%	0.014%	.....
Na:	.....	.....	.....	100.000%	.....	.....
O :	20.210%	.....	.....	79.790%	.....	.....
Pb:	99.873%	.....	.....	0.127%	.....	.....
S :	26.034%	.....	.....	73.964%	0.002%	.....
Sb:	.....	.....	.....	100.000%	.....	.....
Si:	0.000%	.....	.....	100.000%	0.000%	.....
Zn:	97.237%	.....	.....	2.763%	.....	.....

PRODUCTS 2	Gas	Dust	Solids	Slag	Metal	Matte
Al:	.....	.....	.....	100.000%	.....	.....
Ca:	.....	.....	.....	100.000%	.....	.....
Cd:	.....	.....	.....	100.000%	.....	.....
Cr:	.....	.....	.....	100.000%	.....	.....
Cu:	.....	.....	.....	100.000%	.....	.....
F :	.....	.....	.....	100.000%	.....	.....
Fe:	.....	.....	.....	100.000%	.....	.....
K :	.....	.....	.....	100.000%	.....	.....
Mg:	.....	.....	.....	100.000%	.....	.....
Mn:	.....	.....	.....	100.000%	.....	.....
N :	99.010%	.....	.....	0.990%	.....	.....
Na:	.....	.....	.....	100.000%	.....	.....
O :	0.001%	.....	.....	99.999%	.....	.....
Pb:	.....	.....	.....	100.000%	.....	.....
S :	.....	.....	.....	100.000%	.....	.....
Sb:	.....	.....	.....	100.000%	.....	.....
Si:	.....	.....	.....	100.000%	.....	.....
Zn:	.....	.....	.....	100.000%	.....	.....

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Theoretical process based on pyrosim

Temp (C)	1450					1350					1250				
Coke	ZnO	FeO	Met mass	Fe	Fe	ZnO	FeO	Met mass	Fe	Fe	ZnO	FeO	Met mass	Fe	Fe
%	%	%	kg	%	kg	%	%	kg	%	kg	%	%	kg	%	kg
2.0	9.359	37.716	4	29.574	1.2	12.455	36.102	11.1	47.580	5.3	14.559	34.880	14.5	55.006	7.98
2.5	6.659	38.702	6.2	38.218	2.4	9.578	37.083	12.3	50.266	6.2	11.906	35.794	16.0	59.115	9.46
3.0	4.455	39.379	9.4	46.246	4.3	6.915	38.015	13.8	53.909	7.4	9.422	36.500	18.9	65.143	12.31
3.5	2.747	39.766	12.9	53.435	6.9	4.629	38.665	16.0	60.200	9.6	7.397	36.691	24.7	73.365	18.12
4.0	1.560	39.708	17.9	64.012	11.5	3.047	38.588	22.9	71.280	16.3	6.046	36.102	35.1	81.189	28.50
4.5	1.019	38.605	29.8	77.973	23.2	2.297	37.422	35.9	81.672	29.3	5.169	34.899	48.7	86.382	42.07
5.0	0.814	36.731	46.5	85.852	39.9	1.912	35.643	52.3	87.362	45.7	4.514	33.339	63.8	89.538	57.13
5.5	0.691	34.551	64.5	89.756	57.9	1.643	33.582	69.6	90.458	63.0	3.965	31.526	79.5	91.552	72.78
6.0	0.594	32.174	82.7	91.979	76.1	1.421	31.310	87.1	92.342	30.4	3.478	29.515	95.5	92.905	88.72
6.5	0.511	29.617	100.8	93.395	94.1	1.225	28.851	104.6	93.590	97.9	3.028	27.308	111.6	93.875	104.76
7.0	0.436	26.876	118.8	94.368	112.1	1.047	26.215	121.9	94.466	115.2	2.609	24.929	127.6	94.581	120.69
7.5	0.368	23.971	136.4	95.068	129.7	0.882	23.405	139.1	95.106	132.3	2.212	22.369	143.5	95.112	136.49

14 APPENDIX D – Campaign Data

Table D-1. Operating parameters

Tap	Power	Voltage	Batch mass	Period(min)			Tot Energy	Losses #	SER !	Temp	Fuming rate* (kgZn/hm^2)	
No.	kW	V	kg	Tap- tap	Feed	Down	kWh	kW	kWh/kg feed	C	Tap period	Feed period
1	400	100	1060	185	164	0	1150	97	0.641	1421	47.6	53.7
2	400	150	530	92	78	0	561	94	0.534	1393	49.7	58.7
3	400	150	530	109	79	0	600	85	0.700	1421	37.6	51.9
4	725	250	1060	95	71	0	891	91	0.621	1335	30.0	40.2
5	725	250	1060	97	68	0	869	108	0.533	1260	53.7	76.7
6	725	250	1060	92	72	3	900	120	0.584	1241	42.5	54.3
7	725	250	1060	87	75	0	949	122	0.529	1232	54.4	63.1
8	725	250	1060	81	68	0	939	121	0.604	1231	64.8	77.2
9	725	250	1060	261	35	8	859	112	0.519	1160	14.6	108.7
10	725	250	1060	85	66	0	891	103	0.769	1285	57.0	73.4
11	725	250	1060	85	73	0	930	118	0.705	1224	62.1	72.4
12	725	250	530	56	39	0	500	155	0.659	1233	43.7	62.7
13	725	250	530	62	45	0	619	153	0.862	1358	43.8	60.4
14	725	250	530	59	41	0	551	154	0.735	1308	52.3	75.3
15	725	250	530	76	45	0	687	161	0.891	1349	45.4	76.7
16	725	250	1050	99	86	0	1077	168	0.742	1343	64.6	74.3
17	725	250	1050	96	86	0	1080	175	0.743	1340	66.1	73.8
18	725	250	1050	137	90	19	1189	176	0.693	1348	53.3	81.1
19	725	200	1050	113	85	0	1119	156	0.760	1380	59.6	79.3
20	725	200	1050	124	92	12	1150	138	0.814	1421	57.9	78.0
21	725	200	1050	157	83	6	1180	127	0.785	1501	48.5	91.7
22	725	200	1050	102	76	0	990	123	0.743	1543	69.6	93.5
23	725	200	1050	114	75	27	910	112	0.601	1471	63.2	96.1
24	725	200	1050	86	70	3	869	102	0.674	1468	78.8	96.8
25	725	200	1050	156	79	56	981	105	0.680	1446	44.1	87.1
26	725	200	1050	114	68	0	920	114	0.667	1427	59.5	99.7
27	725	200	1050	81	64	0	939	118	0.734	1425	86.1	108.9
28	725	200	1050	75	61	0	789	119	0.601	1410	87.1	107.1
29	725	200	1050	232	68	118	1080	105	0.635	1397	27.2	92.9
30	725	200	1050	69	61	0	745	109	0.579	1374	88.3	99.9
31	725	200	1050	74	61	0	779	108	0.617	1429	81.0	98.2

Table D-1. Operating parameters (continued)

Tap No.	Power kW	Voltage V	Batch mass kg	Period(min)			Tot Energy kWh	Losses # kW	SER ! kWh/kg feed	Temp C	Fuming rate* (kgZn/hm^2)	
				Tap- tap	Feed	Down					Tap period	Feed period
32	725	200	1050	76	61	4	740	107	0.567	1356	79.4	99.0
33	725	200	1050	70	61	0	740	106	0.576	1383	84.1	96.6
34	725	200	1050	69	61	0	740	102	0.582	1296	79.7	90.1
35	725	200	1050	100	62	0	750	105	0.545	1261	29.3	47.3
36	1000	200	1050	49	46	2	740	113	0.608	1354	120.0	127.9
37	1000	200	1050	45	45	0	740	111	0.620	1358	137.1	137.1
38	1000	200	1050	50	42	7	731	109	0.615	1358	108.7	129.4
39	1000	200	1050	130	56	30	949	101	0.694	1334	42.6	98.9
40	1000	200	1050	46	44	0	738	103	0.627	1368	113.3	118.4
41	1000	200	1050	46	44	0	738	105	0.626	1351	123.7	129.3
42	1000	200	1050	57	52	0	879	105	0.746	1387	96.3	105.6
43	1000	200	1050	56	53	0	891	115	0.744	1418	115.7	122.3
44	1000	200	1050	84	55	10	941	123	0.738	1459	79.7	121.8
45	1000	200	1050	52	48	0	828	130	0.683	1447	117.0	126.8
46	1000	200	1050	52	49	0	840	133	0.686	1457	127.2	135.0
47	1500	200	1050	72	23	0	590	133	0.610	1453	61.2	191.7
48	725	200	1138	80	78	0	910	132	0.796	1357	65.5	67.2
49	725	200	1138	93	93	0	1070	134	0.675	1320	58.0	58.0
50	725	200	1138	101	101	0	1191	146	0.690	1315	62.1	62.1
51	725	200	1138	97	97	0	1126	164	0.745	1264	40.2	40.2
52	725	200	1138	95	95	0	1121	173	0.727	1267	50.2	50.2
53	725	200	1138	128	121	5	1410	175	0.902	1333	45.0	47.6
54	525	200	525	73	71	0	621	172	0.788	1309	34.9	35.9
55	525	200	525	156	93	15	900	156	0.934	1412	22.9	38.5
56	525	200	530	62	60	0	520	157	0.651	1348	52.9	54.7
57	525	200	535	115	82	17	720	156	0.772	1331	28.6	40.1
58	525	200	525	85	74	0	660	164	0.833	1300	33.6	38.6
59	800	200	500	40	31	0	440	181	0.634	1252	52.5	67.7
60	960	200	1030	104	65	3	1119	177	0.778	1430	58.0	92.9
61	525	200	1050	160	125	0	1050	173	0.563	1280	28.6	36.6

Note: * Conservative fuming rate based on average final crucible diameter (1.286 m)
! SER (specific energy requirement) is the calculated net energy requirement for the process excluding measured thermal losses
Thermal losses as measured

Table D-2. Materials fed

Tap No.	Slag (kg)	Coke (kg)	Dolomite (kg)	Coke/Slag (%)	Dolomite /slag (%)
Warmup	-	16.3	0		-
1	1270.4	54.1	0	4.26	-
2	749.6	30.2	0	4.03	-
3	605.4	29.6	0	4.89	-
4	1162.5	39.8	0	3.42	-
5	1229.7	71.1	0	5.78	-
6	1161.8	64.2	0	5.53	-
7	1380.4	78.4	0	5.68	-
8	1219.7	65.1	0	5.34	-
9	676.9	39.9	0	5.89	-
10	907.7	62.4	0	6.87	-
11	1006.7	75.7	0	7.52	-
12	509.9	29.3	0	5.75	-
13	508.2	27.3	0	5.37	-
14	518.5	25.5	0	4.92	-
15	517.3	24.9	0	4.82	-
16	1021.6	56.5	0	5.53	-
17	1021.2	55.0	0	5.39	-
18	1081.1	56.6	0	5.23	-
19	1022.8	62.5	0	6.11	-
20	1008.8	55.0	0	5.45	-
21	1023.8	57.3	0	5.60	-
22	993.6	58.4	0	5.88	-
23	1104.3	55.4	0	5.02	-
24	1019.7	53.3	0	5.23	-
25	990.9	50.4	0	5.09	-
26	1005.3	47.6	0	4.73	-
27	1011.3	50.6	0	5.00	-
28	1009.2	54.8	0	5.43	-
29	1013.2	50.8	0	5.02	-
30	1018.8	51.1	0	5.01	-
31	995.9	50.7	0	5.09	-
32	1017.2	48.6	0	4.77	-
33	1020.0	49.9	0	4.89	-
34	1013.0	56.3	0	5.56	-
35	1002.5	50.6	0	5.05	-
36	1015.4	51.1	0	5.03	-
37	1012.0	47.6	0	4.70	-
38	989.3	50.5	0	5.10	-
39	1003.1	49.6	0	4.94	-
40	1000.7	50.3	0	5.03	-
41	1001.3	49.7	0	4.96	-
42	995.5	49.6	0	4.98	-
43	1003.3	51.1	0	5.09	-
44	990.7	51.4	0	5.19	-
45	998.0	49.7	0	4.98	-
46	1005.9	50.2	0	4.99	-
47	685.0	20.6	0	3.01	-
48	820.0	48.7	53.7	5.94	6.55

Table D-2. Materials fed (continued)

Tap No.	Slag (kg)	Coke (kg)	Dolomite (kg)	Coke/Slag (%)	Dolomite /slag (%)
49	1113.9	54.3	108.7	4.87	9.76
50	1206.0	57.7	106.4	4.78	8.82
51	1017.0	51.4	87.0	5.05	8.55
52	1023.4	51.7	89.9	5.05	8.78
53	1017.1	59.9	71.2	5.89	7.00
54	480.4	25.3	16.7	5.27	3.48
55	496.0	32.6	0	6.57	-
56	517.5	31.2	0	6.03	-
57	511.5	34.4	0	6.73	-
58	490.2	23.4	0	4.77	-
59	504.4	0	0	0.00	-
60	1015.0	29.6	0	2.92	-
61	995.4	50.7	0	5.09	-
Total	56726.7	2911.2	533.4	5.13	

Table D-3. Slag masses and analyses

Tap No.	Mass (kg)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Cr_2O_3 (%)	MnO (%)	FeO (%)	CoO (%)	NiO (%)	CuO (%)	ZnO (%)	PbO (%)	As (%)	Cd (ppm)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (ppm)	Total (%)
1	519	2.08	4.35	21.9	16.6	0.28	0.79	45.3	<0.06	<0.06	0.18	3.75	0.22										95.45
2	591	2.06	4.45	23.5	18.3	0.24	0.70	41.0	<0.06	<0.06	0.19	4.75	0.30										95.44
3	375	2.23	5.40	24.8	18.9	0.32	0.69	40.1	<0.06	<0.06	0.17	3.15	0.25										96.01
4	1641	1.83	4.07	23.3	18.5	0.19	0.58	37.4	<0.06	<0.06	0.17	9.63	0.51										96.15
5	907	1.67	4.15	23.1	17.7	0.12	0.55	35.7	<0.06	<0.06	0.18	11.90	0.38	<0.008	<5	1.64	0.39	0.40	0.09	0.08	0.008	<2.5	98.05
6	968	1.78	4.42	23.6	18 6	0.12	0.56	33.5	<0.06	<0.06	0.17	13.10	0.31	<0.008	<5	1.64	0.39	0.40	0.09	0.08	0.008	<2.5	98.76
7	1105	1.73	4.41	23.4	19.1	0.10	0.55	32.0	<0.06	<0.06	0.16	13.70	0.34	<0.008	<5	1.64	0.39	0.40	0.09	0.08	0.008	<2.5	98.09
8	833	1.89	5.20	24.7	19.5	0.10	0.56	31.8	<0.06	<0.06	0.17	12.60	0.27	<0.008	<5	1.64	0.39	0.40	0.09	0.08	0.008	<2.5	99.39
9	317	1.92	4.91	26.0	20.0	0.06	0.62	31.0	<0.06	<0.06	0.18	10.80	0.22	<0.008	<5	1.64	0.39	0.40	0.09	0.08	0.008	<2.5	98.31
10	907	2.27	5.80	28.2	21.8	0.11	0.63	30.9	<0.06	<0.06	0.21	5.83	0.15										95.90
11	598	2.24	5.63	26.4	20.9	0.12	0.60	29.6	<0.06	<0.06	0.18	10.20	0.27	<0.008	<5	1.64	0.39	0.40	0.09	0.08	0.008	<2.5	98.74
12	350	2.25	5.65	26.1	20.7	0.12	0.60	29.6	<0.06	<0.06	0.18	10.60	0.24										96.04
13	682	2.64	7.44	31.2	24.5	0.23	0.68	24.6	<0.06	<0.06	0.10	4.31	0.17	<0.008	<5	1.40	0.45	0.45	0.07	0.08	0.004	<2.5	98.32
14	314	2.62	6.64	29.1	23.6	0.22	0.64	26.0	<0.06	<0.06	0.13	6.85	0.19	<0.008	<5	1.40	0.45	0.45	0.07	0.08	0.004	<2.5	98.44
15	335	3.14	7.74	31.8	25.2	0.37	0.70	24.0	<0.06	<0.06	0.09	3.42	0.05	<0.008	<5	1.40	0.45	0.45	0.07	0.08	0.004	<2.5	98.96
16	713	2.96	7.41	29.9	23.3	0.38	0.66	25.4	<0.06	<0.06	0.11	4.78	0.12	<0.008	<5	1.40	0.45	0.45	0.07	0.08	0.004	<2.5	97.47
17	704	2.81	8.22	28.7	22.3	0.41	0.64	27.0	<0.06	<0.06	0.14	4.99	0.14	<0.008	<5	1.40	0.45	0.45	0.07	0.08	0.004	<2.5	97.80
18	726	2.83	8.42	30.5	23.7	0.42	0.66	26.1	<0.06	<0.06	0.09	2.97	0.06										95.75
19	914	2.33	6.34	27.0	20.5	0.38	0.60	35.3	<0.06	<0.06	0.18	2.73	0.11										95.47
20	724	2.34	5.83	28.4	21.6	0.48	0.64	35.7	<0.06	<0.06	0.15	1.43	0.20										96.77
21	294	2.70	6.45	30.1	23.0	0.44	0.71	32.5	<0.06	<0.06	0.12	0.60	0.06	<0.008	<5	1.17	0.46	0.46	0.08	0.09	0.007	<2.5	98.94
22	692	2.95	5.66	30.1	23.1	0.49	0.72	31.7	<0.06	<0.06	0.14	1.34	0.08	<0.008	<5	1.17	0.46	0.46	0.08	0.09	0.007	<2.5	98.55
23	768	2.65	5.57	28.0	21.4	0.38	0.65	32.9	<0.06	<0.06	0.16	3.76	0 21	<0.008	<5	1.68	0.47	0.45	0.08	0.08	0.006	<2.5	98.45
24	718	2.36	5.78	27.4	20.9	0.31	0.63	34.2	<0.06	<0.06	0.18	3.25	0.14	<0.008	<5	1.68	0.47	0.45	0.08	0.08	0.006	<2.5	97.92
25	673	2.44	5.56	28.8	22.1	0.31	0.66	35.5	<0.06	<0.06	0.18	2.17	0.08	<0.008	<5	1.68	0.47	0.45	0.08	0.08	0.006	<2.5	100.6
26	886	2.36	5.02	26.8	20.6	0.29	0.62	36.3	<0.06	<0.06	0.19	2.29	0.09	<0.008	<5	1.68	0.47	0.45	0.08	0.08	0.006	<2.5	97.33
27	518	2.24	5.60	25.9	20.0	0.28	0.60	37.8	<0.06	<0.06	0.23	3.17	0.17	<0.008	<5	1.68	0.47	0.45	0.08	0.08	0.006	<2.5	98.76
28	761	2.29	5.53	26.2	20.3	0.30	0.60	35.9	<0.06	<0.06	0.21	3.65	0.18	<0.008	<5	1.68	0.47	0.45	0.08	0.08	0.006	<2.5	97.93
29	728	2.21	5.58	26.9	20.7	0.26	0.62	33.9	<0.06	<0.06	0.20	4.74	0.27										95.38
30	771	1.95	6.47	24.3	18.8	0.23	0.56	37.4	<0.06	<0.06	0.29	5.39	0.33	0.021	<5	1.93	0.41	0.41	0.08	0.08	0.016	<2.5	98.67
31	824	2.01	4.45	24.6	19.1	0.23	0.56	39.1	<0.06	<0.06	0.26	4.81	0.28	0.021	<5	1.93	0.41	0.41	0.08	0.08	0.016	<2.5	98.35
32	715	1.94	4.54	25.2	19.5	0.19	0.58	36.2	<0.06	<0.06	0.23	5.98	0.31	0.021	<5	1.93	0.41	0 41	0.08	0.08	0.016	<2.5	97.62
33	728	1.86	4.60	24.6	19.2	0.17	0.57	37.2	<0.06	<0.06	0.26	6.50	0.35	0.021	<5	1.93	0.41	0.41	0.08	0.08	0.016	<2.5	98.26
34	702	1.80	4.65	24.9	19.2	0.13	0.57	35.2	<0.06	<0.06	0.23	8.04	0.36										95.08

Table D-3. Slag Masses and Analyses (continued)

Tap No.	Mass (kg)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Cr_2O_3 (%)	MnO (%)	FeO (%)	CoO (%)	NiO (%)	CuO (%)	ZnO (%)	PbO (%)	As (%)	Cd (ppm)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (ppm)	Total (%)
35	1223	1.76	4.82	25.2	19.5	0.11	0.58	32.7	<0.06	<0.06	0.19	10.10	0.31										95.27
36	645	1.72	5.47	25.2	19.6	0.13	0.58	35.0	<0.06	<0.06	0.23	7.22	0.35	0.017	<5	1.81	0.44	0.44	0.07	0.07	0.013	<2.5	98.35
37	564	1.75	4.45	25.4	19.9	0.10	0.59	35.8	<0.06	<0.06	0.23	6.76	0.35	0.017	<5	1.81	0.44	0.44	0.07	0.07	0.013	<2.5	98.18
38	793	1.76	4.50	25.6	20.0	0.10	0.59	35.2	<0.06	<0.06	0.23	6.74	0.35	0.017	<5	1.81	0.44	0.44	0.07	0.07	0.013	<2.5	97.92
39	898	1.82	5.40	26.3	20.5	0.12	0.61	34.0	<0.06	<0.06	0.20	5.94	0.27										95.16
40	830	1.74	4.64	25.4	19.7	0.12	0.58	35.6	<0.06	<0.06	0.25	7.44	0.36	0.017	<5	1.81	0.44	0.44	0.07	0.07	0.013	<2.5	98.68
41	666	1.74	4.51	24.9	19.5	0.12	0.58	36.3	<0.06	<0.06	0.25	7.34	0.42	0.017	<5	1.81	0.44	0.44	0.07	0.07	0.013	2.5	98.5
42	891	1.83	5.02	26.2	20.4	0.14	0.60	35.1	<0.06	<0.06	0.22	5.96	0.30										95.7
43	803	1.97	5.19	27.8	20.4	0.19	0.61	35.9	<0.06	<0.06	0.21	3.49	0.20	<0.008	<5	1.67	0.45	0.46	0.06	0.08	0.006	<2.5	98.6
44	680	2.01	4.97	27.7	21.4	0.17	0.64	35.1	<0.06	<0.06	0.20	2.88	0.14	<0.008	<5	1.67	0.45	0.46	0.06	0.08	0.006	<2.5	97.9
45	902	1.99	5.26	27.1	21.0	0.17	0.63	34.3	<0.06	<0.06	0.21	4.17	0.18	<0.008	<5	1.67	0.45	0.46	0.06	0.08	0.006	<2.5	97.7
46	760	1.92	4.98	26.2	20.0	0.18	0.61	36.5	<0.06	<0.06	0.24	3.28	0.25	<0.008	<5	1.67	0.45	0.46	0.06	0.08	0.006	<2.5	96.8
47	543	1.99	4.52	25.7	19.8	0.19	0.6	38.2	<0.06	<0.06	0.27	3.60	0.18										95.0
48	344	2.64	4.60	26.1	21.1	0.14	0.62	33.3	<0.06	<0.06	0.23	7.10	0.3										96.1
49	1030	3.17	4.53	25.3	21.4	0.12	0.63	32.6	<0.06	<0.06	0.22	7.74	0.27	<0.008	<5	1.88	0.39	0.40	0.08	0.08	0.007	<2.5	98.8
50	853	3.27	4.36	24.8	21.1	0.10	0.62	32.4	<0.06	<0.06	0.21	8.73	0.27	<0.008	<5	1.88	0.39	0.40	0.08	0.08	0.007	<2.5	98.7
51	994	3.38	4.43	24.1	20.9	0.08	0.61	31.8	<0.06	<0.06	0.21	10.10	0.25	<0.008	<5	1.88	0.39	0.40	0.08	0.08	0.007	<2.5	98.7
52	832	3.51	4.56	24.0	21.2	0.09	0.62	31.4	<0.06	<0.06	0.20	9.39	0.24	<0.008	<5	1.88	0.39	0.40	0.08	0.08	0.007	<2.5	98.0
53	898	3.95	6.17	25.3	23.0	0.12	0.64	30.7	<0.06	<0.06	0.19	5.60	0.12	<0.008	<5	1.88	0.39	0.40	0.08	0.08	0.007	<2.5	98.6
54	483	3.53	5.92	26.9	23.1	0.12	0.65	29.1	<0.06	<0.06	0.26	5.88	0.18										95.6
55	223	3.93	7.11	34.5	28.5	0.21	0.81	19.0	<0.06	<0.06	0.07	1.71	0.08										95.9
56	315	3.14	6.03	31.0	24.8	0.19	0.72	24.3	<0.06	<0.06	0.12	5.10	0.21	<0.008	<5	1.44	0.49	0.47	0.05	0.08	0.005	<2.5	98.
57	416	2.81	5.89	30.5	24.1	0.18	0.71	27.7	<0.06	<0.06	0.13	3.54	0.14	<0.008	<5	1.44	0.49	0.47	0.05	0.08	0.005	<2.5	98.2
58	377	2.35	5.30	28.3	22.2	0.14	0.65	30.3	<0.06	<0.06	0.18	5.85	0.22	<0.008	<5	1.44	0.49	0.47	0.05	0.08	0.005	<2.5	98.0
59	457	2.24	5.53	25.6	20.3	0.20	0.60	29.6	<0.06	<0.06	0.21	9.92	0.37										94.
60	855	2.20	5.51	25.5	19.9	0.25	0.59	37.0	<0.06	<0.06	0.23	4.95	0.27										96.
61	1161	2.10	5.11	25.5	20.2	0.21	0.59	34.8	<0.06	<0.06	0.27	6.69	0.25										95.
Digout1	63	0.59	2.78	11.1	7.26	0.06	0.21	25.6	0.05	<0.06	0.48	0.58	3.45										52.
Digout2	spl	28.9	6.64	12.45	8.38	10.1	0.33	27.3	0.06	0.06	0.69	1.86	1.17	0.31							0.155		98.
Tot/Ave	43513	2.35	5.42	26.58	20.93	0.21	0.63	33.14	<0.06	<0.06	0.19	5.97	0.23	<0.010	<5	1.66	0.43	0.43	0.07	0.08	0.008	<2.5	97.

Note: **Digout1** consisted of loose excess coke containing 58,2% Ash, 0.08% moisture, <0.01% volatiles and 41.85% fixed carbon.
Digout2 is slag material removed from the furnace hearth
Ave is the mean analysis for taps 1 to 61. **spl** indicates that only a sample was taken

Table D-4. Fume masses and analyses

Tap No.	Mass (kg)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Cr_2O_3 (%)	MnO (%)	FeO (%)	CoO (%)	NiO (%)	CuO (%)	ZnO (%)	PbO (%)	As (%)	Cd (%)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (%)	Total (%)
1																							
2	190	0.09	0.13	0.45	0.32	0.029	0.099	1.14	<0.06	<0.06	0.03	77.3	10.5										90.13
3																							
4	378	0.08	0.12	0.55	0.33	0.015	0.060	0.79	<0.06	<0.06	0.04	77.9	11.7										91.53
5	370	0.19	0.52	2.36	1.59	0.012	0.079	3.00	<0.06	<0.06	0.10	68.4	15.9										92.10
6	250	0.24	0.64	3.09	2.07	0.007	0.085	3.50	<0.06	<0.06	0.13	66.3	17.5	0.402	0.108	1.34	0.32	0.72	0.30	0.70	0.162	0.012	97.62
7	165	0.26	0.46	1.91	1.19	0.023	0.150	2.94	<0.06	<0.06	0.11	64.1	15.4	0.402	0.108	1.34	0.32	0.72	0.30	0.70	0.162	0.012	90.60
8	spl	0.65	0.95	3.36	2.44	0.010	0.115	3.23	<0.06	<0.06	0.14	67.2	15.4										93.50
9																							
10	375	0.30	0.68	3.09	1.98	0.007		3.41	<0.06	<0.06	0.13	71.3	13.4										94.30
11																							
12																							
13	386	0.43	0.56	2.52	1.70	0.007	0.090	2.70	<0.06	<0.06	0.15	70.7	15.0	0.344	0.052	1.08	0.30	0.63	0.19	0.17	0.189	0.009	96.82
14																							
15																							
16	510	0.73	0.75	4.07	2.69	0.080	0.150	4.53	<0.06	<0.06	0.18	66.0	14.0	0.344	0.052	1.08	0.30	0.63	0.19	0.17	0.189	0.009	96.09
17																							
18	572	0.62	0.85	4.62	3.06	0.010	0.160	4.98	<0.06	<0.06	0.18	66.2	12.9										93.53
19	348	0.23	0.38	2.31	1.53	0.007	0.065	2.79	<0.06	<0.06	0.11	71.4	13.9										92.67
20	570	0.26	0.52	2.72	1.83	0.007	0.090	3.32	<0.06	<0.06	0.11	70.0	16.1										94.96
21	spl	0.08	0.06	0.47	0.36	0.007	0.060	0.52	<0.06	<0.06	0.04	77.1	17.0	0.114	0.056	1.05	0.08	0.35	0.25	0.10	0.089	0.010	97.79
22	spl	0.08	0.09	0.48	0.37	0.007	0.060	0.40	<0.06	<0.06	0.04	80.4	15.1	0.114	0.056	1.05	0.08	0.35	0.25	0.10	0.089	0.010	99.12
23																							
24	580	0.10	0.17	1.09	0.63	0.007	0.060	1.19	<0.06	<0.06	0.06	75.6	16.8	0.212	0.058	1.22	0.13	0.42	0.35	0.20	0.105	0.009	98.41
25	443	0.08	0.07	0.53	0.24	0.007	0.060	0.44	<0.06	<0.06	0.04	81.0	14.1	0.212	0.058	1.22	0.13	0.42	0.35	0.20	0.105	0.009	99.27
26	291	0.08	0.14	0.65	0.34	0.007	0.060	0.68	<0.06	<0.06	0.05	79.7	14.3	0.212	0.058	1.22	0.13	0.42	0.35	0.20	0.105	0.009	98.71
27																							
28																							
29	353	0.08	0.08	0.46	0.32	0.007	0.060	0.30	<0.06	<0.06	0.04	81.8	13.7										96.85
30	448	0.09	0.26	1.33	0.89	0.007	0.060	1.48	<0.06	<0.06	0.06	73.3	15.4	0.120	0.064	1.18	0.11	0.39	0.24	0.16	0.096	0.008	95.24
31																							
32	430	0.11	0.28	1.49	0.92	0.007	0.060	1.63	<0.06	<0.06	0.06	73.6	15.5	0.120	0.064	1.18	0.11	0.39	0.24	0.16	0.096	0.008	96.02
33	359	0.08	0.11	0.61	0.43	0.007	0.060	0.51	<0.06	<0.06	0.04	78.7	14.5	0.120	0.064	1.18	0.11	0.39	0.24	0.16	0.096	0.008	97.40
34	spl	0.10	0.26	1.21	0.65	0.007	0.060	0.95	<0.06	<0.06	0.13	79.2	14.6										97.11

Table D-4. Fume masses and analyses (continued)

Tap No.	Mass (kg)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	CaO (%)	Cr_2O_3 (%)	MnO (%)	FeO (%)	CoO (%)	NiO (%)	CuO (%)	ZnO (%)	PbO (%)	As (%)	Cd (%)	S (%)	Na (%)	K (%)	Cl (%)	F (%)	Sb (%)	Bi (%)	Total (%)
35	338	0.16	0.35	1.69	0.97	0.007	0.060	1.39	<0.06	<0.06	0.15	77.9	13.9										96.57
36	spl	0.08	0.19	0.72	0.46	0.007	0.060	0.60	<0.06	<0.06	0.05	76.4	14.9										93.47
37	spl	0.08	0.43	1.09	1.49	0.020	0.060	1.44	<0.06	<0.06	0.08	76.1	14.5										95.29
38	411	0.08	0.33	1.25	0.83	0.090	0.060	1.44	<0.06	<0.06	0.08	75.7	14.6	0.262	0.072	1.13	0.09	0.34	0.26	0.12	0.116	0.008	96.85
39																							
40																							
41	465	0.08	0.14	0.79	0.36	0.070	0.060	0.63	<0.06	<0.06	0.04	77.4	16.3	0.262	0.072	1.13	0.09	0.34	0.26	0.12	0.116	0.008	98.26
42																							
43	490	0.08	0.13	0.76	0.31	0.007	0.060	0.36	<0.06	<0.06	0.040	74.9	19.2	0.325	0.050	1.28	0.07	0.37	0.22	0.13	0.123	0.010	98.43
44																							
45																							
46																							
47	624	0.08	0.18	0.87	0.40	0.007	0.060	0.65	<0.06	<0.06	0.040	76.5	16.9										95.69
48																							
49	386	0.26	0.45	2.21	1.28	0.007	0.060	2.16	<0.06	<0.06	0.120	72.9	15.8	0.390	0.069	1.09	0.18	0.55	0.27	0.15	0.127	0.008	98.08
50	305	0.35	0.56	2.13	1.27	0.007	0.070	1.93	<0.06	<0.06	0.150	72.7	15.3	0.390	0.069	1.09	0.18	0.55	0.27	0.15	0.127	0.008	97.30
51	346	0.40	0.48	2.67	1.70	0.007	0.070	2.41	<0.06	<0.06	0.100	71.7	14.9										94.44
52	379	0.41	0.48	2.66	1.80	0.007	0.070	2.43	<0.06	<0.06	0.100	71.5	15.2	0.390	0.069	1.09	0.18	0.55	0.27	0.15	0.127	0.008	97.49
53	spl	0.52	0.58	3.06	2.22	0.007	0.090	3.20	<0.06	<0.06	0.135	72.5	12.0										94.31
54	410	0.37	0.45	2.46	1.75	0.007	0.075	2.32	<0.06	<0.06	0.105	69.9	14.6										92.03
55	spl	0.38	0.54	3.18	1.92	0.008	0.095	2.90	<0.06	<0.06	0.125	68	15.6										92.75
56																							
57	337	0.39	0.76	3.82	2.78	0.008	0.103	4.18	<0.06	<0.06	0.115	67.9	14.8	0.264	0.052	1.05	0.17	0.46	0.21	0.12	0.097	0.008	97.28
58																							
59																							
60																							
61	364	0.12	0.19	1.20	0.66	0.007	0.060	1.28	<0.06	<0.06	0.065	73.7	17.2										94.47
End	242	0.23	0.38	1.81	1.10	0.016	0.073	1.97	<0.06	<0.06	0.087	75.5	15.8										
Combust	37	0.41	0.55	2.20	1.40	0.066	0.079	2.29	<0.06	<0.06	0.14	74.7	15.1										
Accretion1	spl	0.36	1.05	4.90	3.65	0.014	0.100	6.06	<0.06	<0.06	0.14	61.7	20.4										
Accretion2	spl	0.72	2.34	10.6	7.20	0.026	0.220	13.40	<0.06	<0.06	0.36	58.8	5.93										
Total/Avg	12150	0.23	0.376	1.84	1.21	0.015	0.077	1.94	<0.06	<0.06	0.091	73.5	15.0	0.263	0.066	1.16	0.16	0.47	0.26	0.21	0.122	0.009	95.59

Note: **Combust** is material collected from the dropout box below the combustion chamber
Accretion1 is material collected from inside the offgas ducting
Accretion2 is material that dropped out of the offgas ducting nearest the furnace ducting.
spl indicates that only a sample was taken. **Avg** is the mean analysis for taps 1 to end

Table D-5. Accumulative elemental mass balance

(feed less products)

Tap No.	Mg (kg)	Al (kg)	Si (kg)	Ca (kg)	Cr (kg)	Mn (kg)	Fe (kg)	Cu (kg)	Zn (kg)	Pb (kg)	As (kg)	Cd (kg)	S (kg)	Na (kg)	K (kg)	Cl (kg)	F (kg)	Sb (kg)	Bi (kg)
Warmup	0.00	0.00	0.00	0.00	0.00	0.00	500.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.000
1	4.23	12.40	66.59	76.74	-0.40	1.17	115.78	2.98	131.53	32.35	4.36	-0.05	10.81	1.847	2.166	0.686	-0.089	1.037	0.005
2	-1.03	0.39	5.73	4.21	-0.63	-0.67	-12.53	1.29	40.11	14.26	2.53	-0.07	1.12	-0.259	-0.227	0.088	-0.553	0.526	-0.002
3	0.01	0.87	26.70	30.63	-0.55	0.51	58.58	1.22	-29.49	-0.95	2.01	-0.18	1.13	-0.129	-0.552	-0.194	-1.151	0.251	-0.015
4	-8.33	-13.28	-69.57	-90.74	-1.59	-3.42	-204.25	1.15	-56.51	10.88	3.83	-0.16	-10.90	-3.650	-3.767	-0.495	-1.729	0.690	-0.011
5	0.91	3.02	14.97	15.18	-0.18	0.19	29.68	2.03	-90.37	-16.29	4.08	-0.35	0.33	-0.479	-1.373	-0.635	-2.311	0.525	-0.029
6	-1.07	-1.37	-2.20	-8.34	-0.26	-0.41	9.89	1.83	-48.53	-4.39	3.89	-0.23	-0.53	-0.645	-1.105	-0.419	-1.585	0.648	-0.016
7	-0.04	0.68	8.93	-1.70	-0.08	-0.10	46.89	2.52	17.48	19.35	4.68	-0.13	2.29	-0.075	-0.086	-0.040	-0.907	0.98	-0.003
8	0.39	0.12	17.65	14.74	0.01	0.52	78.53	2.33	46.16	21.05	3.77	-0.02	4.95	0.584	0.759	0.293	0.120	0.884	0.004
9	1.86	4.51	24.09	26.76	0.19	0.74	79.92	1.41	10.77	6.56	1.91	-0.04	4.55	0.724	0.652	0.188	0.084	0.397	-0.003
10	-4.91	-10.43	-34.51	-44.08	-0.25	-1.36	-6.99	1.03	33.25	13.71	2.66	-0.03	-1.46	-1.144	-1.057	0.081	-0.224	0.572	-0.001
11	0.17	1.72	21.26	18.96	-0.01	0.63	97.27	1.96	41.29	14.43	3.03	-0.03	5.42	0.755	0.824	0.274	0.124	0.688	0.001
12	-0.74	-0.91	4.29	2.27	-0.05	0.06	37.01	0.85	-20.13	-1.55	1.31	-0.05	1.16	-0.132	-0.276	0.046	-0.095	0.223	-0.005
13	-6.87	-17.36	-52.67	-65.59	-0.83	-1.91	-13.27	0.80	-14.21	-1.91	1.28	-0.05	-2.62	-1.702	-1.847	-0.188	-0.362	0.224	-0.006
14	-1.30	-1.68	3.18	0.31	-0.32	0.05	52.77	0.96	-23.17	-5.21	1.20	-0.07	2.24	-0.134	-0.410	0.002	-0.127	0.170	-0.009
15	-2.68	-4.38	-3.97	-7.12	-0.69	-0.21	53.53	1.04	-15.29	-4.85	1.20	-0.07	1.93	-0.231	-0.507	-0.014	-0.145	0.168	-0.009
16	-4.78	-8.77	-5.79	-10.59	-1.46	-0.29	94.12	2.14	48.36	11.46	2.93	-0.05	4.91	-0.194	-0.193	0.251	-0.054	0.643	-0.003
17	-4.31	-12.08	-3.64	-7.10	-1.50	-0.29	81.94	1.82	-14.44	-0.83	3.19	-0.12	3.85	0.137	-0.084	-0.136	-0.053	0.709	-0.016
18	-4.26	-12.67	-7.08	-11.34	-1.59	-0.31	96.52	2.26	6.18	1.70	3.39	-0.12	2.63	0.390	0.202	-0.088	-0.024	0.736	-0.015
19	-4.61	-11.36	-21.55	-26.10	-1.90	-0.86	-16.94	1.40	-53.60	-11.28	3.09	-0.16	-2.03	-0.665	-1.055	-0.435	-0.281	0.609	-0.023
20	-3.26	-8.39	-9.65	-9.22	-2.49	-0.48	-673.01	-17.09	-165.86	-62.80	-21.77	-0.28	-23.37	-0.067	-1.073	-0.873	-0.362	-6.364	-0.049
21	3.86	9.85	55.66	63.06	-0.40	1.88	166.64	2.69	74.93	11.39	3.39	-0.04	11.81	2.072	2.238	0.478	0.389	0.843	-0.001
22	-3.92	-1.40	-3.03	-6.18	-1.85	-0.47	63.47	2.11	60.16	12.57	3.26	-0.04	6.68	0.137	0.286	0.128	0.008	0.786	-0.002
23	-2.97	-1.40	3.42	2.30	-1.47	-0.09	62.58	2.21	67.96	13.02	3.50	-0.04	3.37	0.012	0.352	0.038	-0.043	0.870	0.000
24	-1.63	-2.32	4.06	3.29	-1.04	-0.03	48.20	1.91	58.68	10.74	3.20	-0.04	2.85	-0.045	0.239	-0.011	-0.069	0.791	-0.001
25	-1.69	-0.78	2.26	0.99	-0.97	-0.20	46.38	1.82	-139.09	-25.16	2.48	-0.22	-0.51	-0.320	-0.926	-1.048	-0.651	0.453	-0.028
26	-4.20	-7.71	-17.09	-21.55	-1.29	-0.89	-498.94	-10.42	-41.66	-8.03	-11.84	-0.13	-19.95	-1.074	-1.188	-0.672	-0.507	-3.699	-0.017
27	1.55	4.18	32.92	36.05	-0.51	1.06	86.07	2.00	73.60	18.21	3.36	-0.04	8.44	0.933	1.263	0.365	0.186	0.835	0.003
28	-1.98	-2.72	2.41	-0.62	-1.08	-0.08	25.34	1.66	64.13	17.69	3.33	-0.04	2.35	-0.218	0.159	0.168	-0.010	0.817	0.003
29	-1.14	-1.92	4.31	2.59	-0.81	-0.03	46.88	1.79	59.39	17.27	3.33	-0.04	3.09	0.244	0.471	0.272	0.020	0.812	0.003
30	-0.64	-7.30	6.21	4.65	-0.75	-0.01	10.90	1.01	-131.70	-32.12	2.87	-0.25	-3.52	-0.116	-0.810	-0.622	-0.539	0.435	-0.023
31	-1.66	-0.44	-1.81	-5.31	-0.83	-0.21	-18.36	1.12	2.69	0.41	3.06	-0.10	-2.16	-0.168	-0.223	-0.130	-0.226	0.628	-0.005
32	0.14	2.14	10.58	9.85	-0.45	0.22	35.86	1.59	3.64	1.21	3.15	-0.10	0.27	0.352	0.310	-0.020	-0.123	0.666	-0.005
33	0.34	1.80	11.94	10.29	-0.37	0.17	28.67	1.40	-99.35	-16.38	2.99	-0.19	-1.62	0.159	-0.285	-0.373	-0.361	0.528	-0.016
34	0.90	2.19	13.60	13.36	-0.15	0.34	45.54	1.53	11.56	8.89	3.03	-0.08	3.03	0.332	0.459	0.133	0.026	0.730	-0.001
35	-4.62	-12.09	-50.31	-62.33	-0.45	-2.09	-76.30	0.90	-42.25	8.38	2.94	-0.09	-5.83	-1.945	-1.824	-0.243	-0.399	0.679	-0.003

Table D-5. Accumulative elemental mass balance (continued)
(feed less products)

Tap No.	Mg (kg)	Al (kg)	Si (kg)	Ca (kg)	Cr (kg)	Mn (kg)	Fe (kg)	Cu (kg)	Zn (kg)	Pb (kg)	As (kg)	Cd (kg)	S (kg)	Na (kg)	K (kg)	Cl (kg)	F (kg)	Sb (kg)	Bi (kg)
36	1.88	0.84	19.80	19.93	-0.09	0.57	63.26	1.76	43.31	13.09	3.09	-0.06	3.40	0.548	0.758	0.258	0.176	0.742	0.002
37	2.59	5.93	28.10	28.68	0.08	0.88	80.05	1.86	49.86	13.75	3.09	-0.06	4.79	0.893	1.101	0.312	0.230	0.749	0.002
38	-0.06	0.05	-1.81	-6.22	-0.15	-0.25	14.87	1.38	34.34	12.12	2.97	-0.06	0.32	-0.191	0.004	0.128	0.053	0.698	0.001
39	-1.40	-6.38	-15.90	-22.60	-0.33	-0.83	-1.60	1.48	23.58	8.02	3.01	-0.07	-0.27	-0.533	-0.376	0.022	-0.122	0.721	-0.001
40	-0.27	-1.12	-4.19	-8.07	-0.27	-0.32	5.63	1.25	16.47	7.42	2.96	-0.07	-0.37	-0.330	-0.174	0.067	0.014	0.683	0.000
41	1.45	3.36	16.79	15.97	-0.14	0.42	47.37	1.58	26.87	7.62	2.99	-0.07	2.59	0.392	0.548	0.182	0.129	0.705	0.000
42	-1.48	-4.58	-15.62	-21.91	-0.39	-0.79	-9.08	1.29	-28.48	-12.67	2.60	-0.09	-1.66	-0.579	-0.756	-0.117	-0.255	0.593	-0.013
43	-1.12	-2.79	-10.07	-8.22	-0.57	-0.42	11.78	1.54	-7.07	-11.42	2.65	-0.08	-0.15	-0.334	-0.587	0.033	-0.178	0.621	-0.012
44	0.11	1.18	5.37	3.66	-0.32	0.00	47.39	1.79	49.20	7.95	2.80	-0.07	3.15	0.079	-0.021	0.219	-0.005	0.720	0.000
45	-2.41	-5.95	-20.29	-27.01	-0.58	-1.00	-5.98	1.38	35.89	7.57	2.81	-0.07	-0.46	-0.897	-1.015	0.093	-0.177	0.713	-0.001
46	-0.31	-0.70	1.69	0.68	-0.46	-0.16	20.87	1.46	47.37	7.58	2.85	-0.07	2.05	-0.228	-0.328	0.187	-0.057	0.730	0.000
47	-0.78	-2.21	-2.04	-2.63	-0.38	-0.21	-312.32	-15.43	-2.33	-5.86	-20.86	-0.08	-13.44	-0.253	-0.453	-0.074	-0.134	-6.411	-0.007
48	7.76	7.18	34.48	47.19	0.06	1.11	101.22	1.60	0.49	-1.69	2.08	-0.10	5.65	1.005	0.742	0.109	0.075	0.523	-0.005
49	2.75	-3.62	-17.60	-14.98	-0.32	-1.24	-1.65	1.29	3.73	6.56	3.06	-0.09	-3.28	-0.522	-0.726	-0.166	-0.245	0.765	-0.002
50	5.78	2.70	12.91	22.49	-0.02	-0.07	64.87	1.76	-41.89	-4.83	2.97	-0.16	0.33	0.286	-0.263	-0.223	-0.199	0.725	-0.010
51	-1.82	-4.48	-19.26	-23.42	-0.07	-1.34	-12.28	1.06	-114.78	-15.96	2.13	-0.20	-5.83	-0.989	-1.809	-0.644	-0.521	0.480	-0.016
52	1.13	-1.23	-0.47	-0.43	-0.04	-0.64	31.04	1.39	-114.29	-20.91	2.04	-0.22	-3.05	-0.396	-1.319	-0.595	-0.436	0.455	-0.018
53	-4.68	-10.11	-11.86	-24.97	-0.26	-1.06	20.47	1.42	5.29	10.36	2.95	-0.07	-2.34	-0.342	-0.467	-0.081	-0.171	0.727	-0.004
54	-4.61	-6.29	-17.47	-26.55	-0.18	-0.88	0.51	0.24	-59.93	-12.43	1.09	-0.09	-2.30	-0.768	-1.098	-0.264	-0.258	0.228	-0.011
55	-1.31	1.04	9.81	7.25	-0.09	0.25	81.59	1.23	16.10	0.25	1.42	-0.04	3.29	0.564	0.511	0.129	0.074	0.354	-0.003
56	-1.82	-0.40	1.64	-1.63	-0.17	-0.05	58.88	1.12	9.83	1.36	1.49	-0.04	2.78	0.051	0.073	0.150	0.017	0.378	-0.003
57	-2.96	-3.37	-12.41	-18.09	-0.27	-0.60	27.45	0.97	9.94	1.23	1.46	-0.04	1.25	-0.465	-0.426	0.093	-0.069	0.367	-0.003
58	-1.24	-1.20	-3.97	-6.80	-0.13	-0.24	25.85	0.86	7.97	1.18	1.47	-0.04	1.53	-0.315	-0.256	0.097	-0.112	0.341	-0.002
59	-1.96	-4.14	-8.54	-11.80	-0.39	-0.41	12.61	0.67	-8.42	0.86	1.51	-0.04	-0.56	-0.384	-0.393	-0.019	-0.165	0.337	-0.002
60	-2.79	-5.75	-7.19	-11.41	-0.98	-0.42	-7.72	1.38	76.84	17.45	3.25	-0.02	1.21	-0.334	-0.062	0.238	-0.085	0.800	0.004
61	-6.30	-12.20	-44.30	-59.28	-1.19	-1.89	-80.33	0.39	45.28	16.24	3.16	-0.02	-4.04	-1.717	-1.456	0.003	-0.345	0.757	0.003
Digout	-0.56	-1.41	-5.30	-5.17	-0.05	-0.24	-16.24	-0.42	-147.01	-54.43	-0.58	-0.16	-3.81	-0.694	-1.455	-0.653	-0.563	-0.344	-0.033
Digout	-0.09	-2.47	-6.55	-0.37	-2.48	-0.02	-826.14	-25.43	-40.18	-60.49	-34.01	-0.03	-10.70	-0.065	-0.181	-0.093	-0.078	-10.841	-0.044
Total(kg)	-72.82	-155.01	-36.35	-197.43	-37.20	-16.73	20.75	18.11	-195.77	13.67	71.06	-5.92	-7.21	-11.23	-18.37	-3.75	-15.43	7.82	-0.477
Percent	113.30	114.11	100.67	103.13	236.55	108.47	99.85	89.18	102.13	99.28	64.21	348.34	100.78	105.74	108.10	106.30	134.87	85.79	160.12

15 APPENDIX E – Energy Losses and Shell Temperatures

Figure E-1. Plot of measured heat losses vs tap number

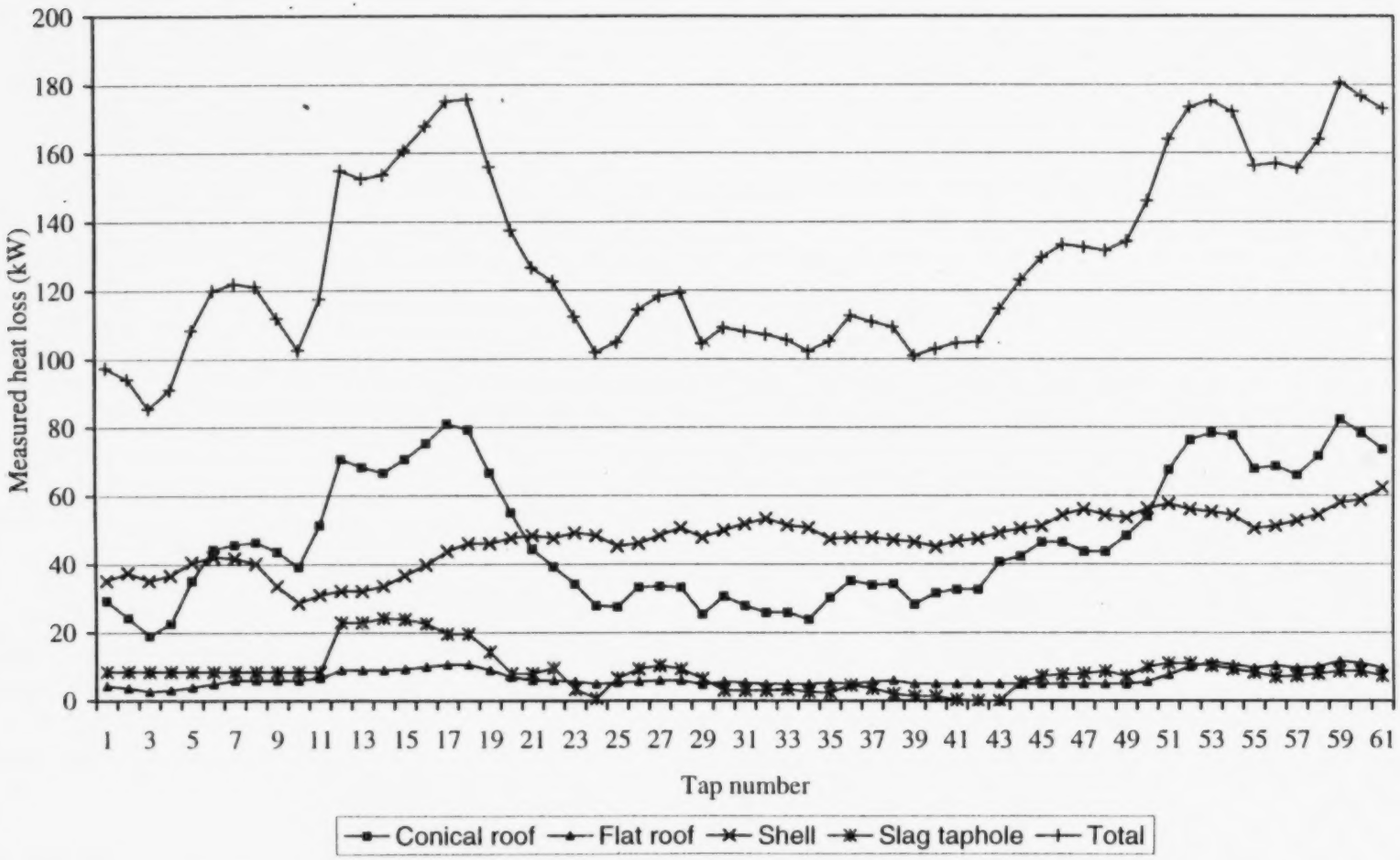
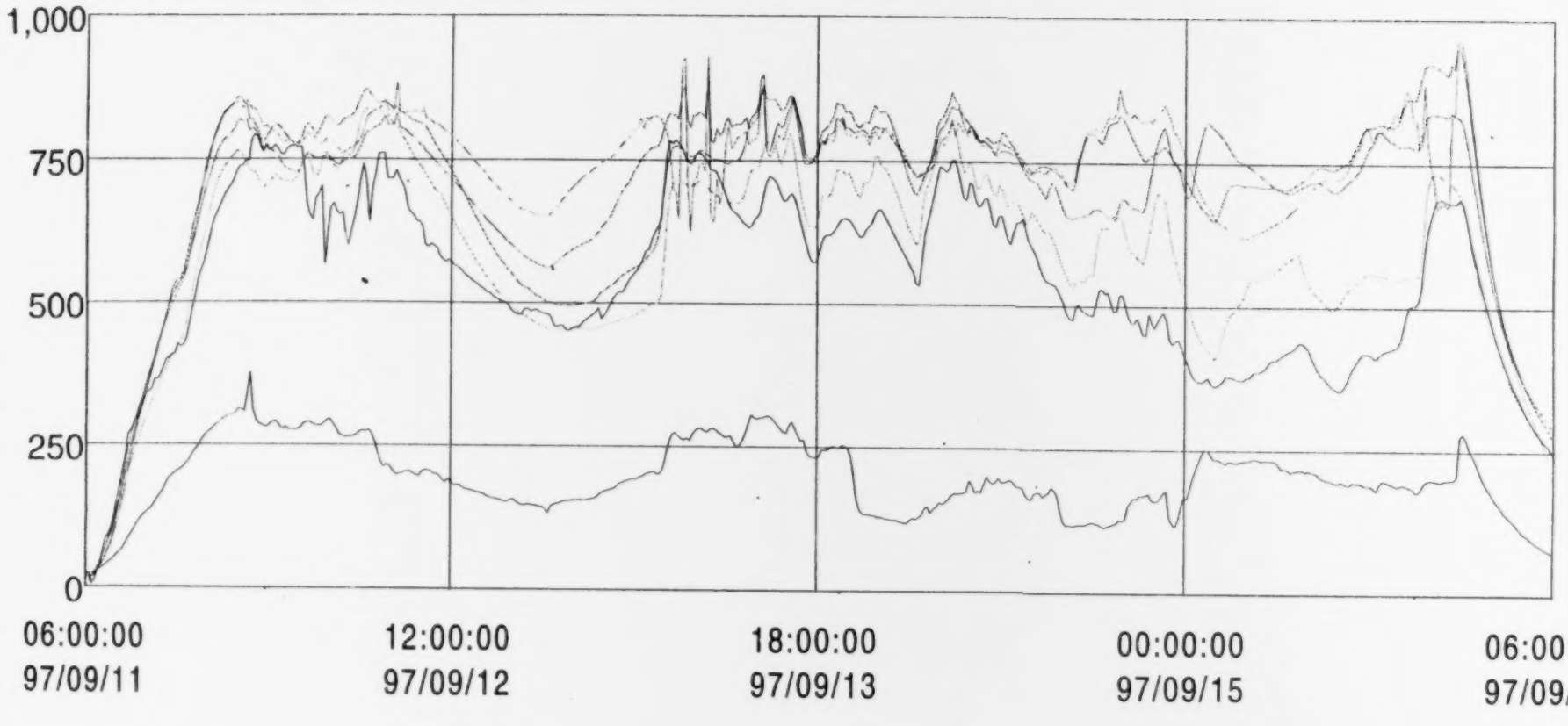


Figure E-2. Shell temperatures



16 APPENDIX F – Furnace Dig-out and Refractory Wear

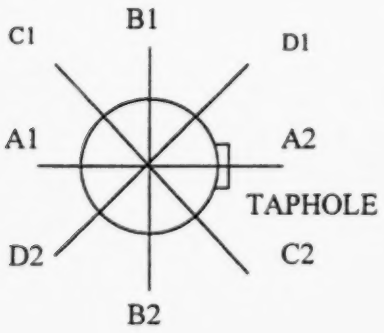
Refractory Wear:

The furnace lining was examined after completion of the campaign and the extent of refractory erosion was determined.

Photographs of the inside of the furnace taken before and during the dig-out are shown in the back of this Appendix. In all the figures, the broomstick serves to indicate the position of the taphole. Figures F-2 and F-3 clearly show the unreacted / partially reacted coke that was found in the furnace at the start of the dig-out. The total mass of the loose coke that was removed from the furnace was 63 kg and the analysis can be found in Appendix D.

Figures F-4 and F-5 were taken when the coke had been removed from the furnace as comparative pictures to Figure F-2. Figures F-4 and F-5 show the banks that had formed from furnace region A2 (taphole) toC2 (See Figure F-1). These banks were found to consist largely of metal (See dig-out metal analysis in Table 10 for composition) with some slag in the upper portion of the banks. However, it was unusually difficult to obtain a dig-out slag sample (See dig-out slag analysis in Appendix D for composition) because even in the uppermost regions of the banks a large amount of metal was interspersed in the slag.

FIGURE F-1: Furnace regions



Figures F-3 and F-4 also show the region of the observation ports i.e. one directly opposite the taphole at A1, and the other very close to D1. These ports were lined with Guntap which is a magnesium rammable refractory. (Only 1,5 bricks were used above the double brick layer at the base of the furnace, with the rest of the shell height having been lined with Guntap). The port regions were moderately eroded. Although the cause of the erosion is uncertain the following factors could all have contributed:

- Erosion due to mechanical wear: this would have occurred during the cleaning of the ports (to facilitate observation of the bath) during the campaign.
- Erosion due to high temperatures: Suction of air into the furnace through the observation ports may have caused zinc fume to burn at the entry point to the furnace interior. This would have caused elevated temperatures on the Guntap surface, which, in turn, could have caused melting of the refractory.
- Erosion by slag: Foaming slag occurred during Tap 10 and may have contributed to erosion of the port areas. The foaming increased the slag level, facilitating contact between the highly erosive slag and the weaker refractory around the ports. Although the maximum height attained by the foaming slag is unknown it did reach the port level as the port at A1 was blocked with slag after this Tap.

Figures F-6 and F-7 show the brick surfaces, giving a general indication of the brick surface at the end of the campaign.

A schematic indication of the extent of the wear on the furnace shell's refactory lining is shown in Figures F-8 to F-11. Following each of these Figures is a photograph of the actual bricks from which these profiles were measured. The method for profile measurement was as follows:

- The bricks from each profile were laid out in the correct order on being removed from the furnace shell.
- With the top of the first brick being taken as the zero point, measurements of the brick thickness were taken at 20 mm intervals down the full length of the profile.
- Knowing that the original brick thickness (114 mm) of the D60/100's (magnesia-chrome refractory bricks produced by Vereeniging Refractories) used, the amount of refractory wear and the worn brick profile could be accurately determined.

Figure F-8 presents some features that are of interest. Firstly, the amount of increased erosion that occurred in the Observation Port region should be noted. Secondly, it would appear that the bricks in the A1 profile were far more severely eroded at a depth of approximately 800 mm than bricks of a similar depth in any of the other profiles. The following hopes to offer some explanation for this. Figure F-4 shows a section of a lance rod that was found fused in the surface of bath material during the dig-out. This rod would almost certainly have broken off in the bath during attempts to completely drain the bath at the end of the last tap. However, its proximity to the A1 region indicates that the Tappers could easily reach the back wall of the furnace with the lance rods. Another rod section was found lower in the dig-out bath material. This rod seems to suggest that the Tappers may have lanced through the entire bath diameter when the bath was not properly molten to the slag taphole level. The presence of an oxygen lance against the refractories on the furnace wall opposite the taphole would have greatly increased refractory wear on this wall. And the increased refractory wear in this region, along with the lance sections found in the bath, would seem to confirm this theory.

None of the bricks examined during the dig-out showed evidence of a protective freeze lining. (This was also noted in previous Doe Run Campaigns: See C2189M and C2370M). It is assumed that the refractory wear occurred as determined in C2189M (pg 50) i.e. "... for an examination which revealed no preferential attack of either the magnesite or chromium containing phases with the dissolution of the refractories into the slag being the source of erosion."

Quantities of lead were found between and behind the bricks and in the Ankerharth in the hearth of the furnace. The exact masses of the lead recovered from each of the regions in the furnace is given in Table F-1 below. This information may hopefully aid in shedding some light on regions of maximum lead buildup to facilitate accurate lead drainage in continuous operations.

Most of the lead found between the bricks had an iridescent surface coating that ranged in colour from deep purple through blue, turquoise and green to gold. Pink was only found on one sample. The sample was analyzed using Energy Dispersive Spectrometry methods on an electron microprobe (see Figures F-12 and F-13 for results) and the surface coating was found to be antimony. The lead found in the hearth regions appeared to have run in cracks in the Ankerharth, coating either side of the crack. This could clearly be seen in some of the samples as it was possible to pull the two layers apart. The lead (still with an antimony coating, but mostly blue-gold-silver in colour) in these regions was particularly crystalline in structure, with a meshwork of interweaving crystals clearly visible to the naked eye.

TABLE F-1: Amount of lead found during the dig-out in various furnace regions

REGION OF FURNACE	MASS OF LEAD / kg
Base of furnace in Ankerharth	4.025
Furnace region A2 – C2	2.323
Furnace region C2 – B2	2.282
Furnace region B2 – D2	1.411
Furnace region D2 – A1	1.316
Furnace region A1 – C1	0.671
Furnace region C1 – B1	1.121
Furnace region B1 – D1	0.956
Furnace region D1 – A2 (Taphole block)	0.844
Furnace region D1 – A2 (Taphole launder)	0.268
Lead that self tapped at the base of the slag taphole (Tap 20)	2.642
Total Lead recovered	**16.859**

Figures F-14 and F-15 show the conical and flat roof refractory wear. As can be seen, no significant erosion of either the conical or the flat roof refractories (a 95% alumina castable) was evident.

Condensed fume accretions were present on the conical and flat roofs and can also be seen in Figures F-14 and F-15. During the campaign, the offgas port had to be cleaned regularly (twice to three times per tap) to avoid blockages from condensed accretions. At one stage accretion buildup was so great that balls of accretion were rolling out of the offgas port – these were collected and analyzed (See accretion analysis in Table D-4 in Appendix D). The feed ports and pipes were not cleaned during taps, and the pipe between the offgas port and the taphole area was found to be blocked when the dig-out started (thus, the exact time that the blockage occurred is unknown).

FIGURE F-2: Photograph of the interior of the furnace shell at the start of the furnace dig-out

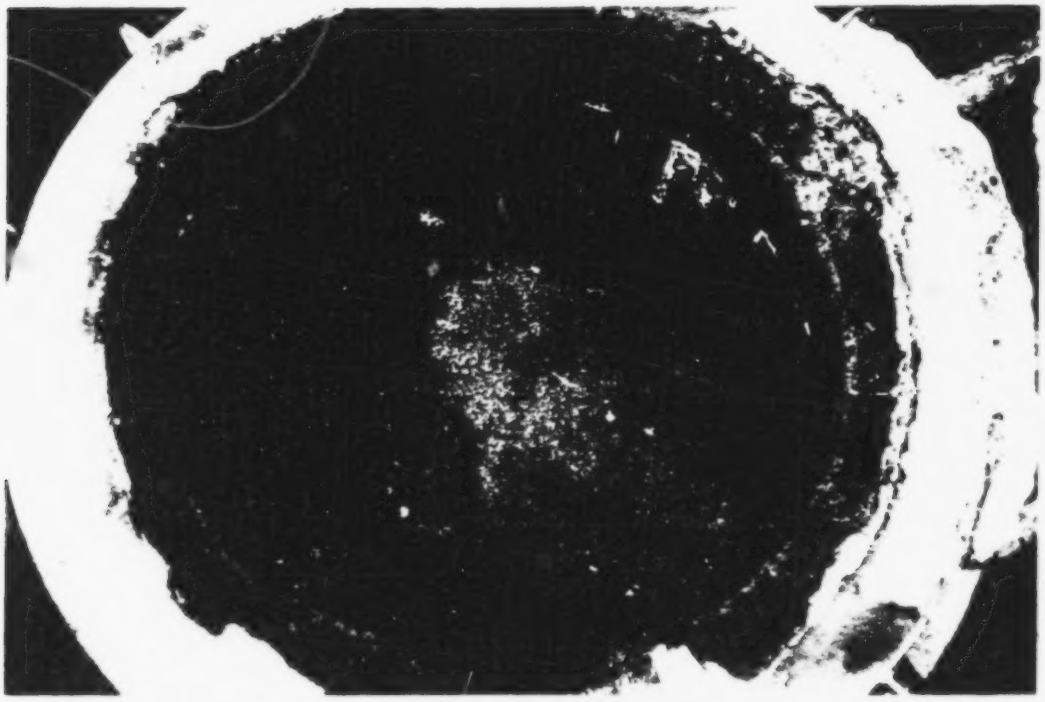


FIGURE F-3: Close-up of the interior of the furnace shell showing the unreacted coke lying on top of the bath (Furnace regions C1 to D1 to C2)

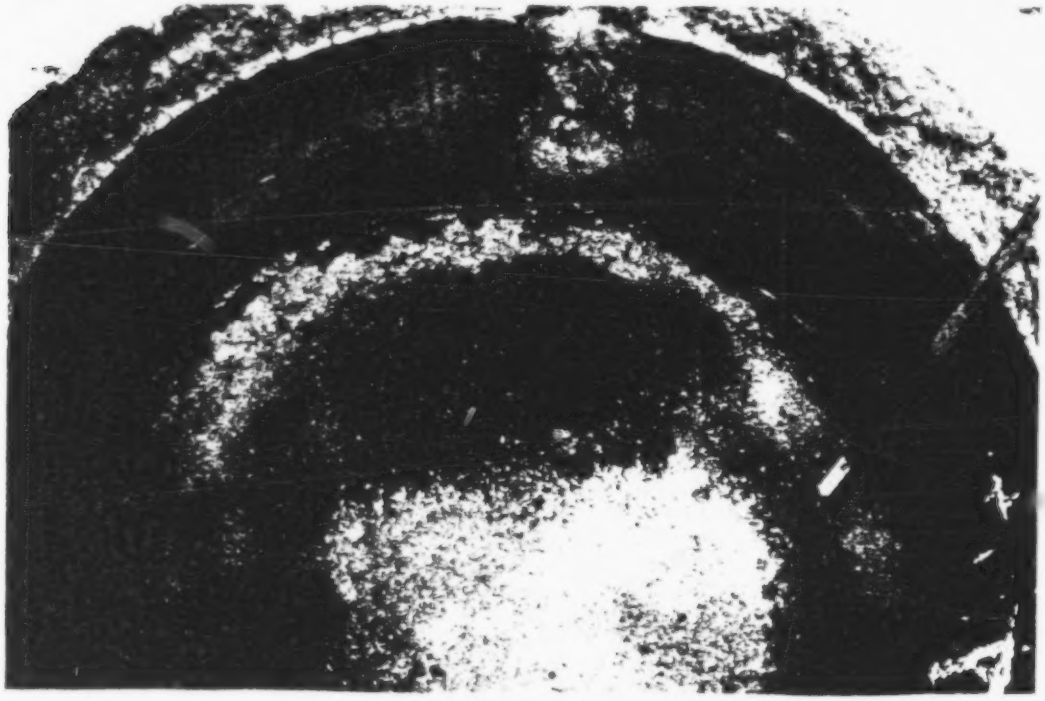


FIGURE F-4: Photograph of the interior of the furnace shell after the coke had been removed (Furnace regions C2 to A1 to D2)

Lance rod

FIGURE F-5: Photograph of the interior of the furnace shell after the coke had been removed (Furnace regions D2 to A2 to C1)

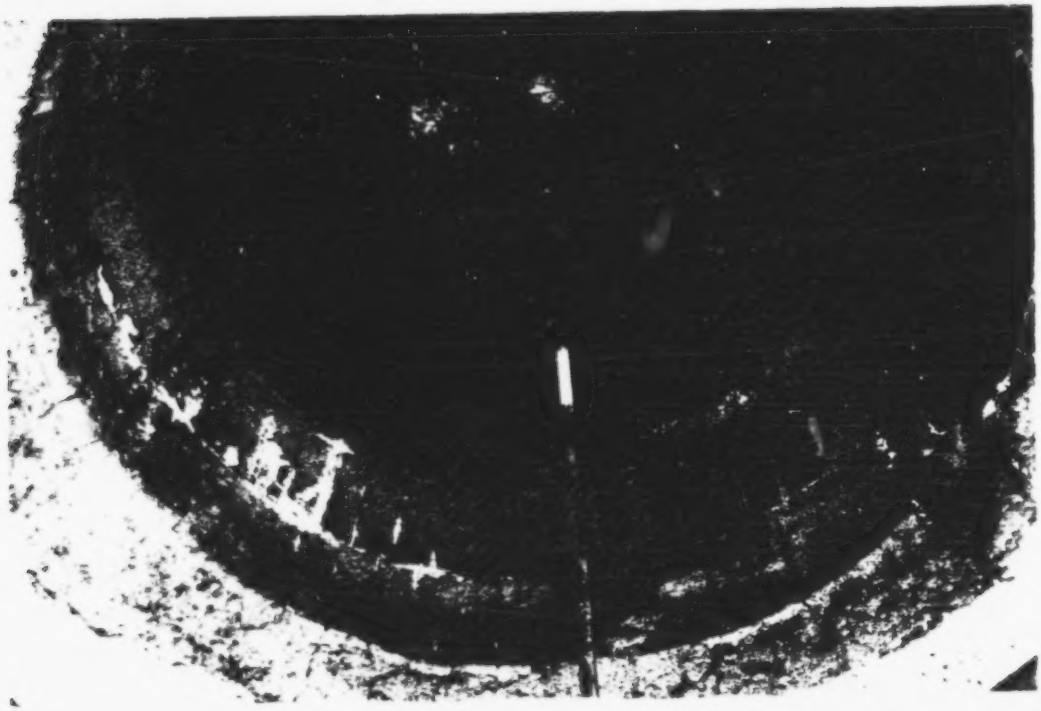


FIGURE F-6: Close-up of the bricks in furnace region D2 to C1 to D1

FIGURE F-7: Close-up of the bricks in furnace region C1 to B2 to C2

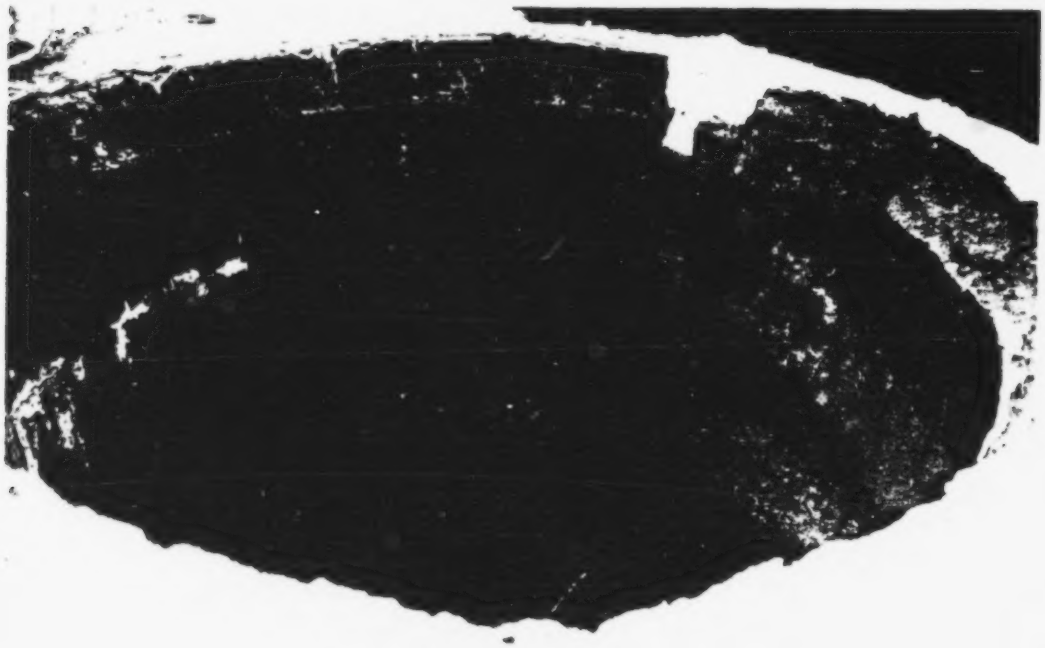
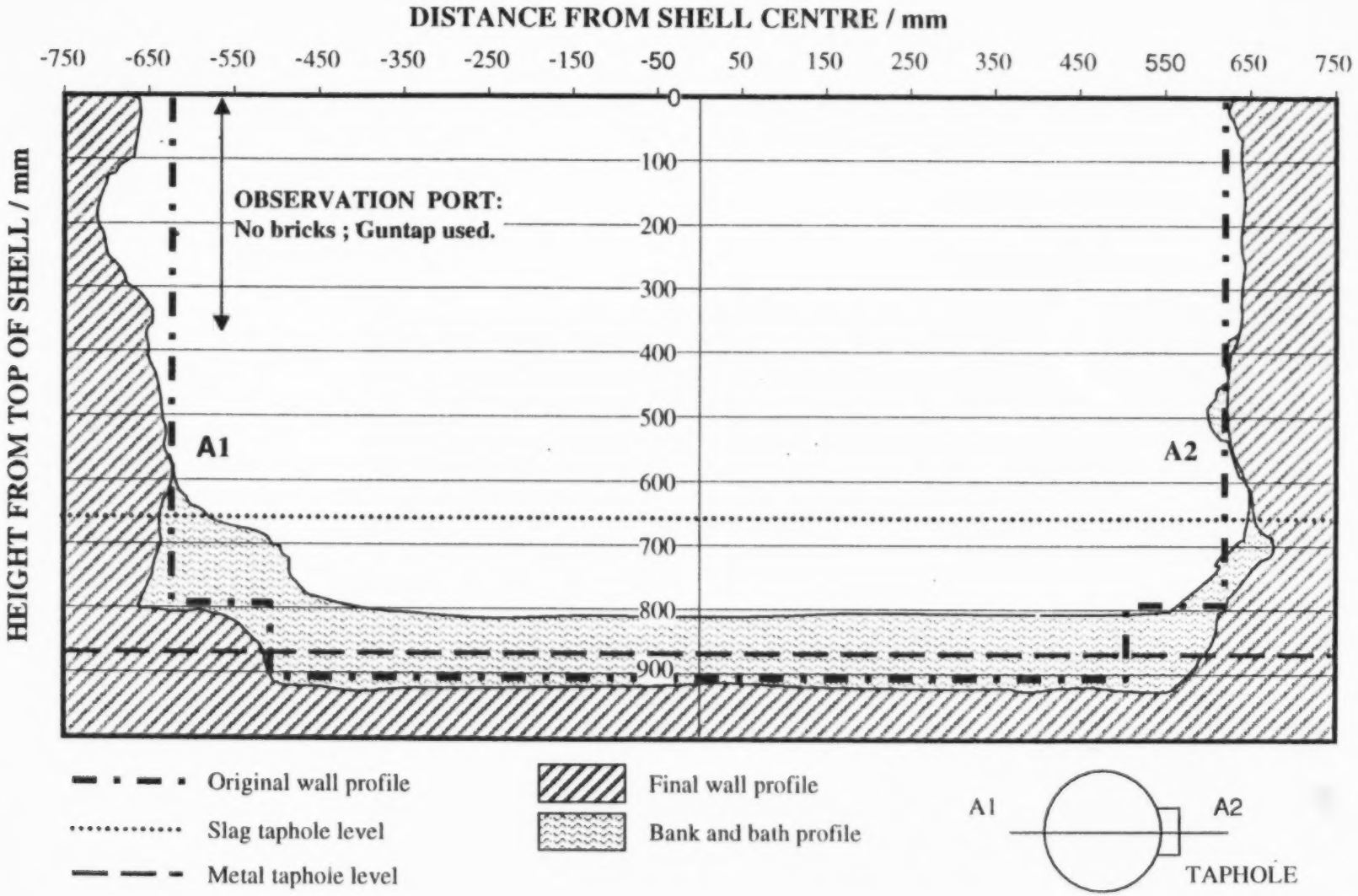


FIGURE F-8; SCHEMATIC OF SECTION A



Photograph of brick profile along cross section A1-A2

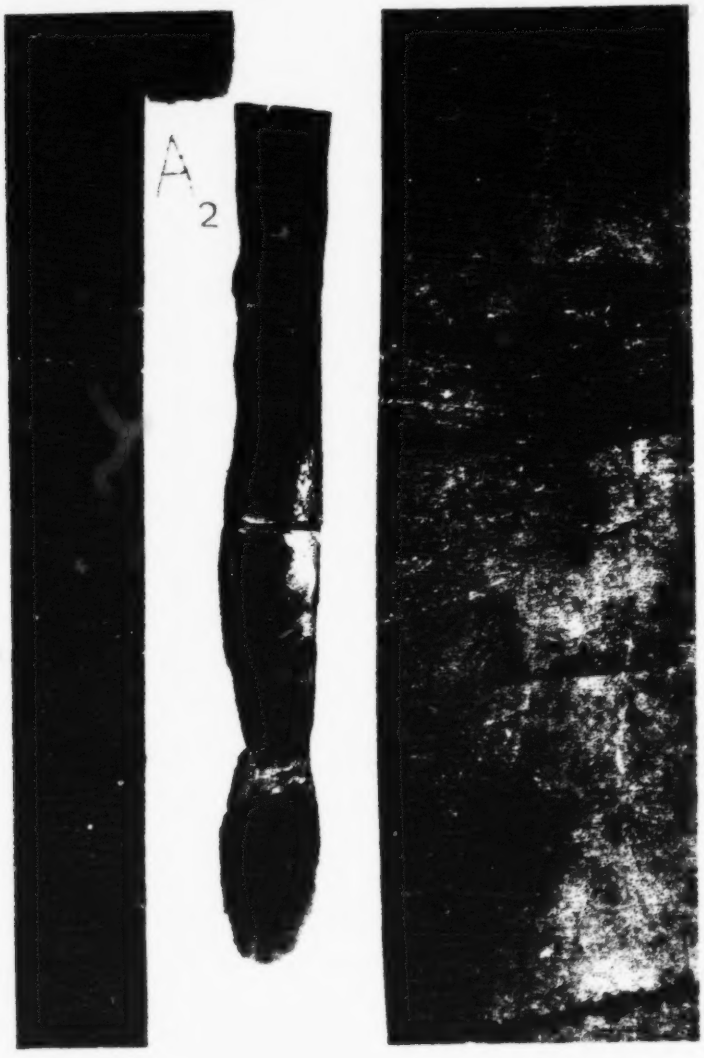
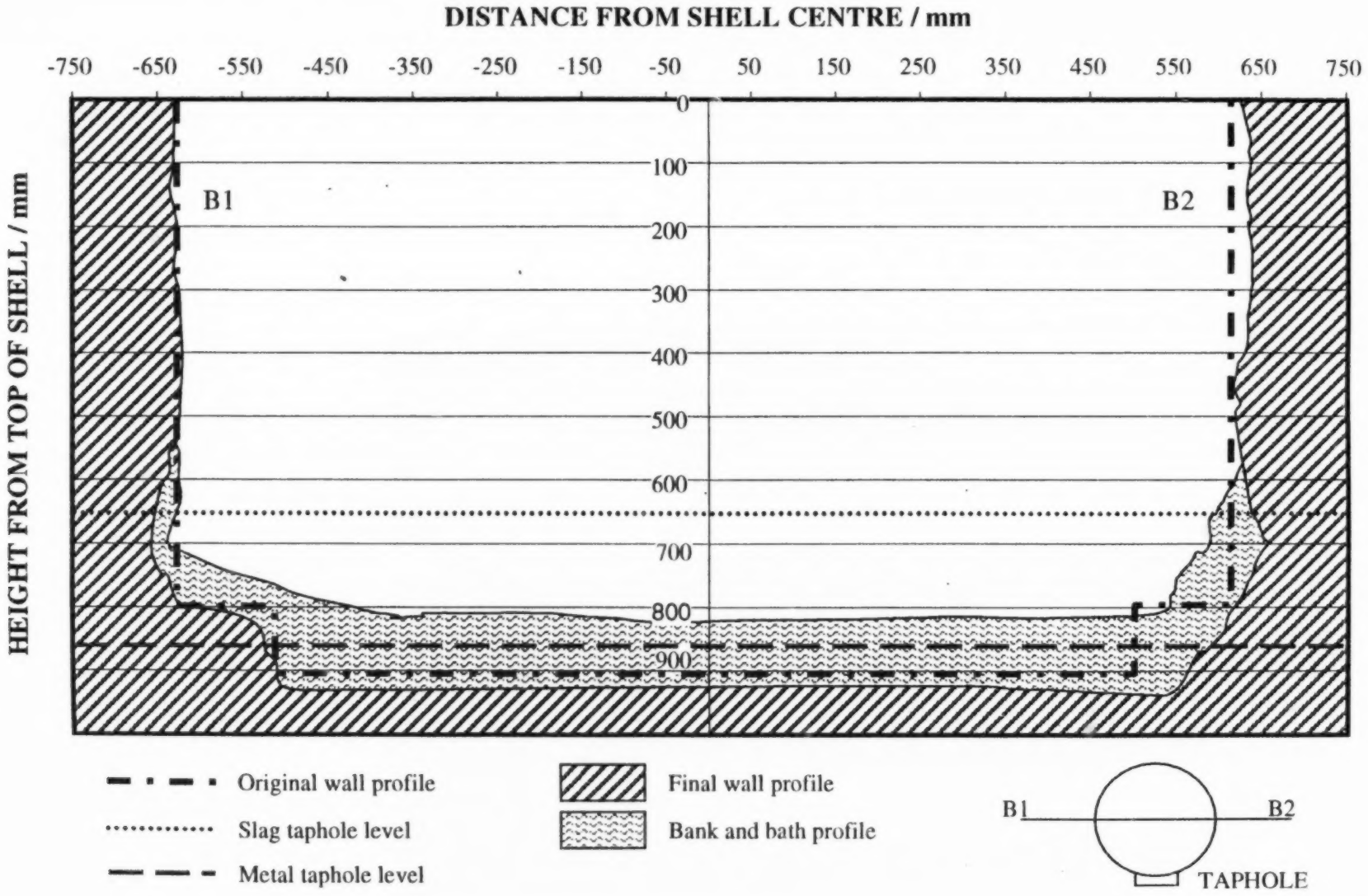
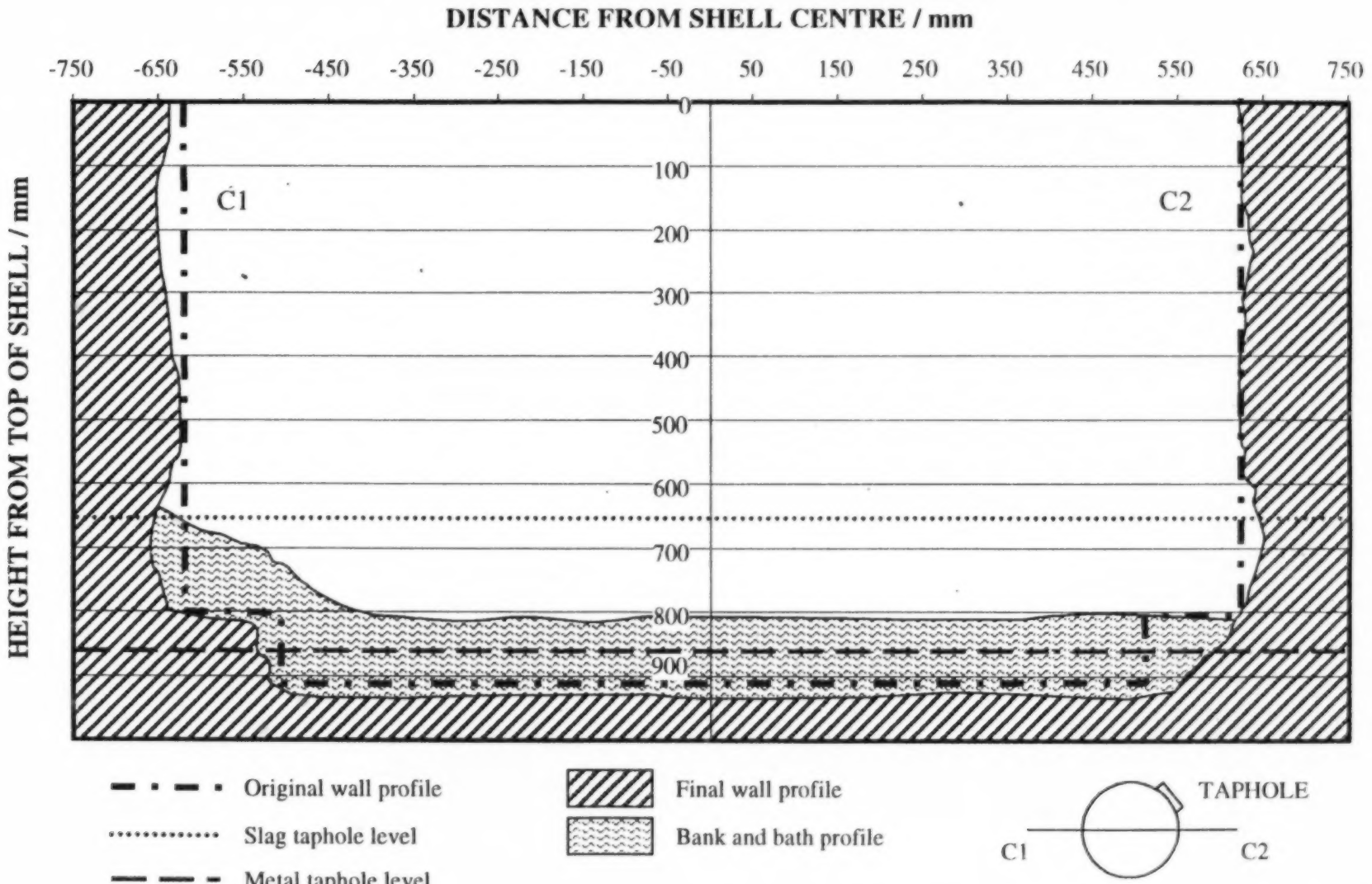


FIGURE F-9: SCHEMATIC OF SECTION B



Photograph of brick profile along cross section B1-B2

FIGURE F-10: SCHEMATIC OF SECTION C



Photograph of brick profile along cross section C1-C2

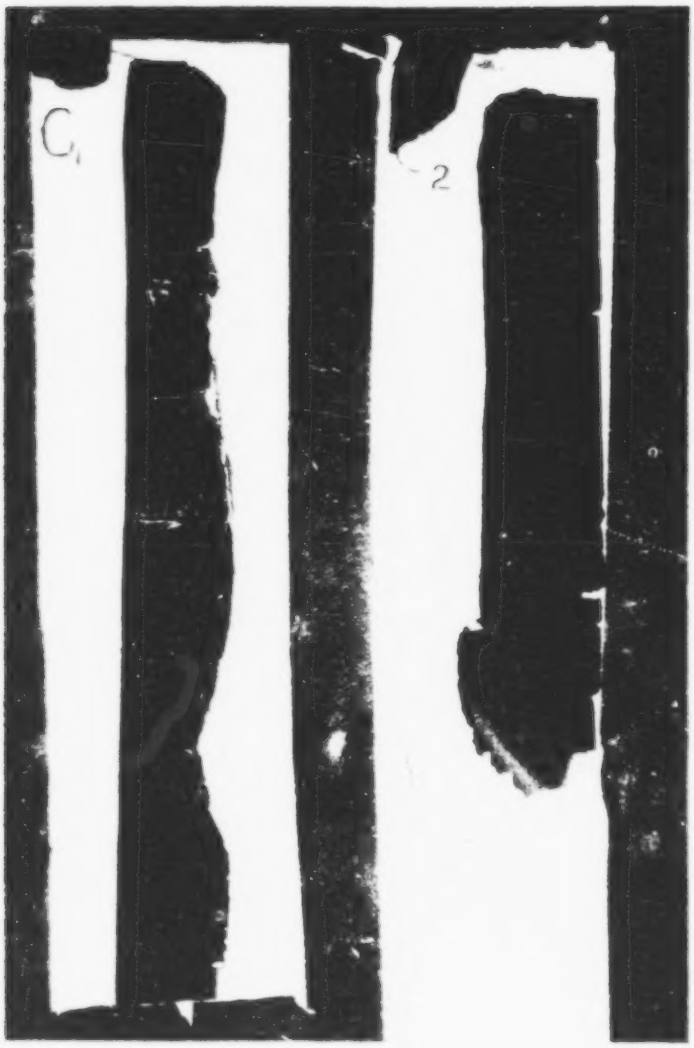
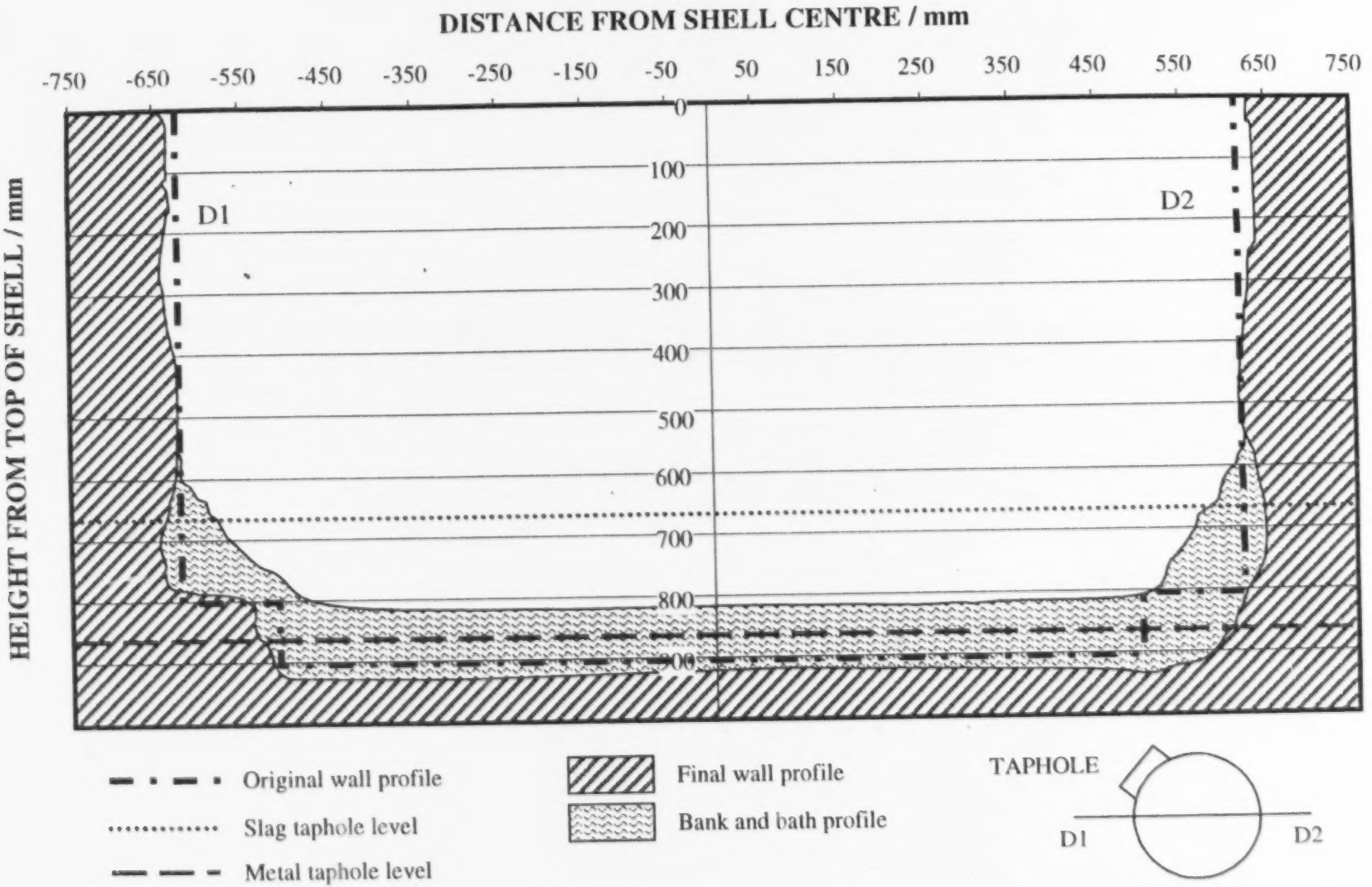


FIGURE F-11: SCHEMATIC OF CROSS SECTION D



Photograph of brick profile along cross section D1-D2

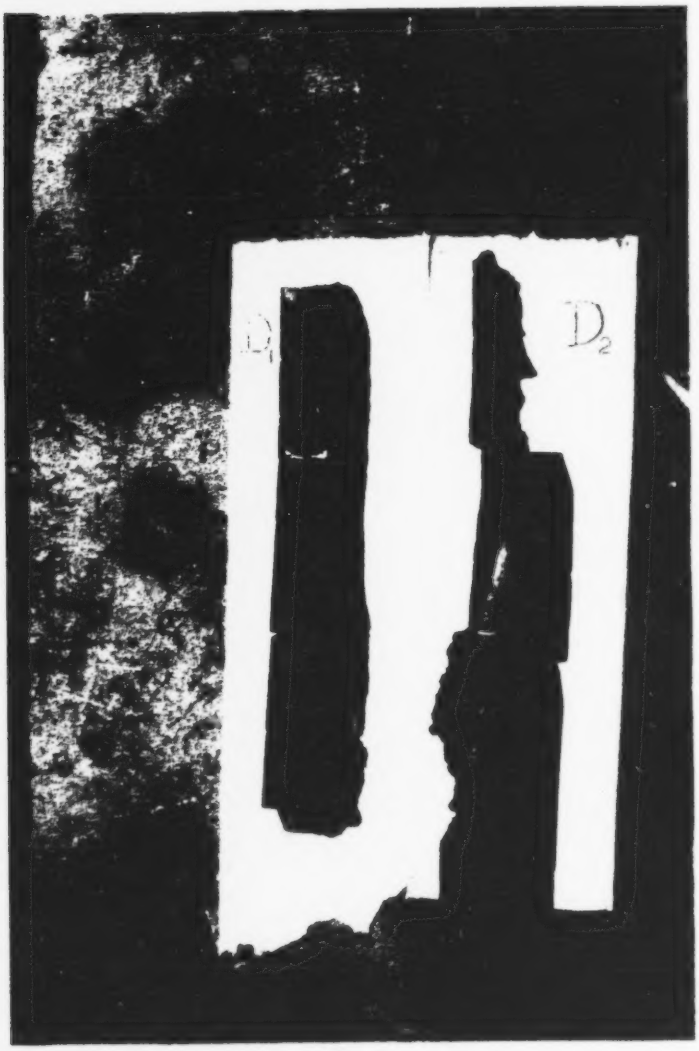
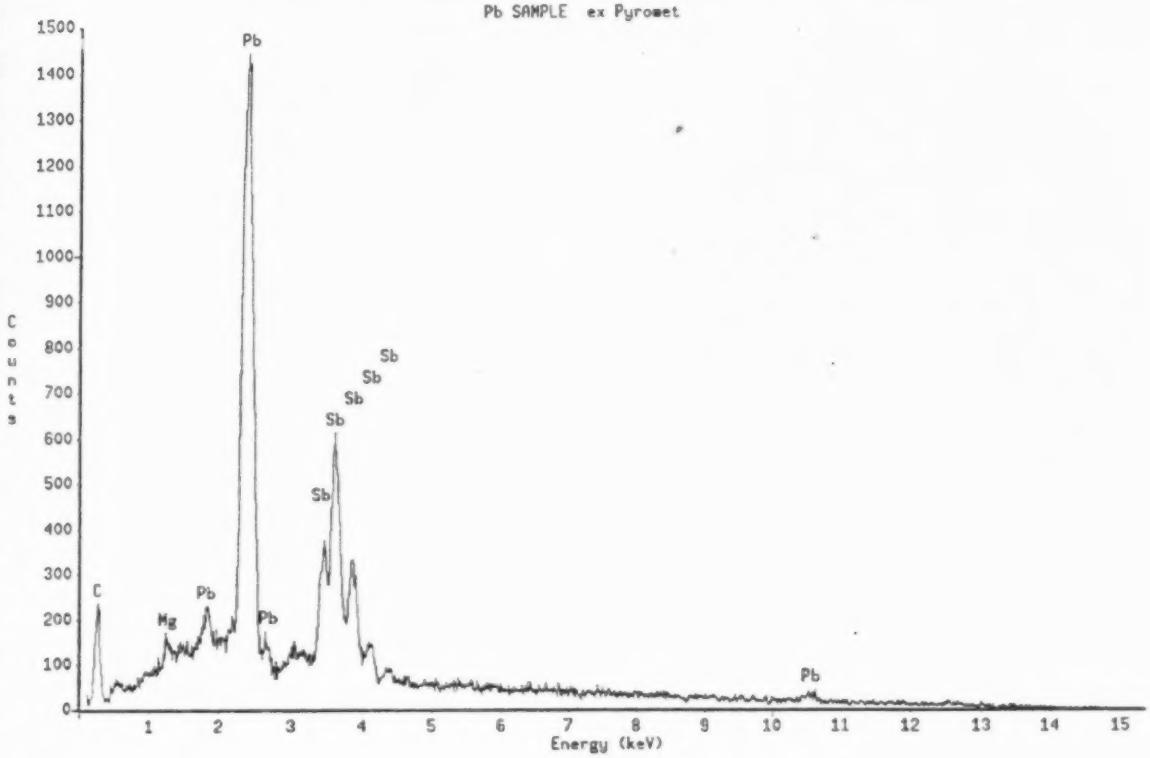


FIGURE F-12: Results of Energy Dispersive Spectrometry test on the surface coating of the sample showing the presence of antimony



Pb SAMPLE ex Pyromet

Column	: JEOL.Pioneer		
Take-off angle	: 40	Accelerating voltage	: 15
Acquisition type	: eds	Magnification	: 1000
Creation time	: 97/10/13 13:05	Charge	: 2019
Livetime	: 100	Beam current	: 20.19
Deadtime	: 29.902	Beam spot size	: 0
Channels	: 2048	Beam location	: 0.499878,0.499878
Channel width	: 10	Working distance	: 11
Detector type	: Silicon/Lithium	Stage X	: 35.264
Window type	: norvar	Stage Y	: 7.973
Window thickness	: 0.3	Stage Z	: 11.923
Coating material	: Al	Stage tilt	: 0
Coating thickness	: 0.04	Stage rotation	: 0
Contact material	: Au	Contamination material	: none
Contact thickness	: 0.02	Contamination thickness	: 0
Crystal thickness	: 3		

File name :

Notes:

Mon Oct 13 13:05:47 1997

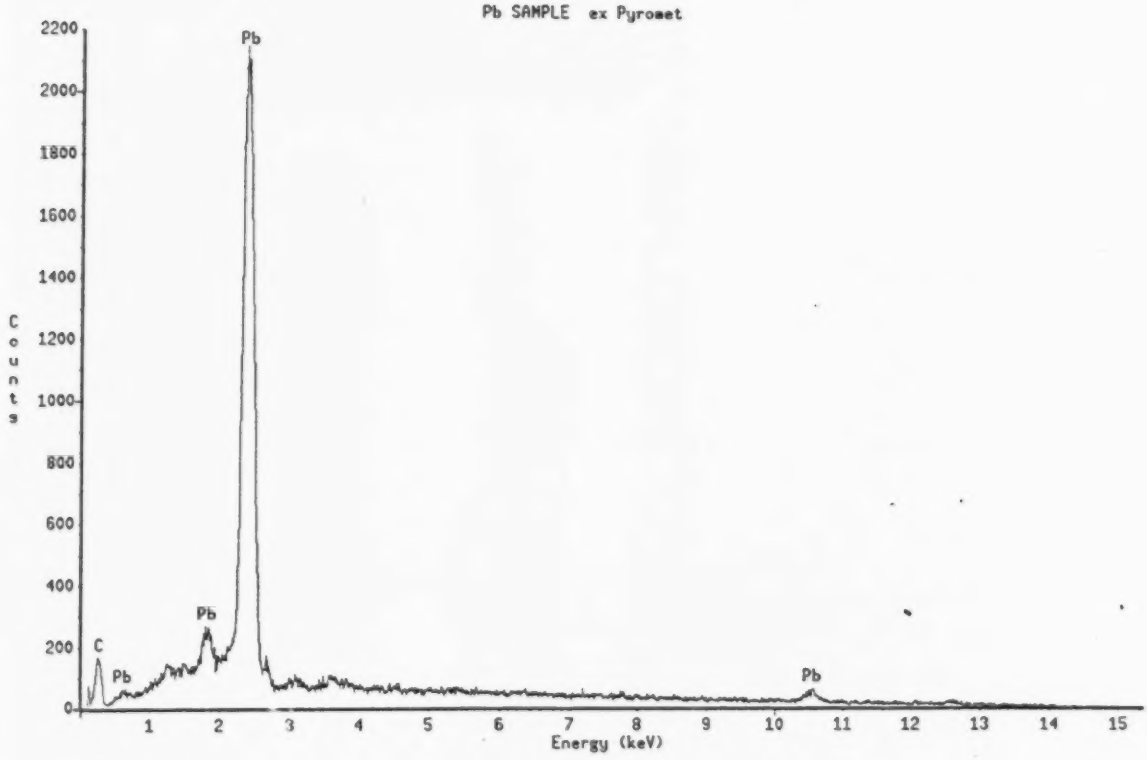
Pb SAMPLE ex Pyromet

Livetime : 100.0 Sec.
Technique: Least Squares Fit

Elements Present:
C (6), Mg(12), Pb(82), Sb(51), Sn(50)

Energy	Intensity	Element
0.265	1555	C Ka
1.266	557	Mg Ka
1.823	1086	Pb Mz1

FIGURE F-13: Results of Energy Dispersive Spectrometry test on the substrate of the sample showing no antimony present



Pb SAMPLE ex Pyromet

Column	: JEOL.Pioneer		
Take-off angle	: 40	Accelerating voltage	: 15
Acquisition type	: eds	Magnification	: 1000
Creation time	: 97/10/13 13:00	Charge	: 2019
Livetime	: 100	Beam current	: 20.19
Deadtime	: 30.388	Beam spot size	: 0
Channels	: 2048	Beam location	: 0.499878,0.499878
Channel width	: 10	Working distance	: 11
Detector type	: Silicon/Lithium	Stage X	: 34.47
Window type	: norvar	Stage Y	: 7.791
Window thickness	: 0.3	Stage Z	: 11.928
Coating material	: Al	Stage tilt	: 0
Coating thickness	: 0.04	Stage rotation	: 0
Contact material	: Au	Contamination material	: none
Contact thickness	: 0.02	Contamination thickness	: 0
Crystal thickness	: 3		

File name :

Notes:

Mon Oct 13 12:56:55 1997

Livetime : 15.1 Sec.
Technique: Least Squares Fit

Elements Present:
Al(13)

Energy	Intensity	Element
1.508	49	Al Ka

FIGURE F-14: Photograph of the conical roof taken during the digout: notice the accretions in the upper regions

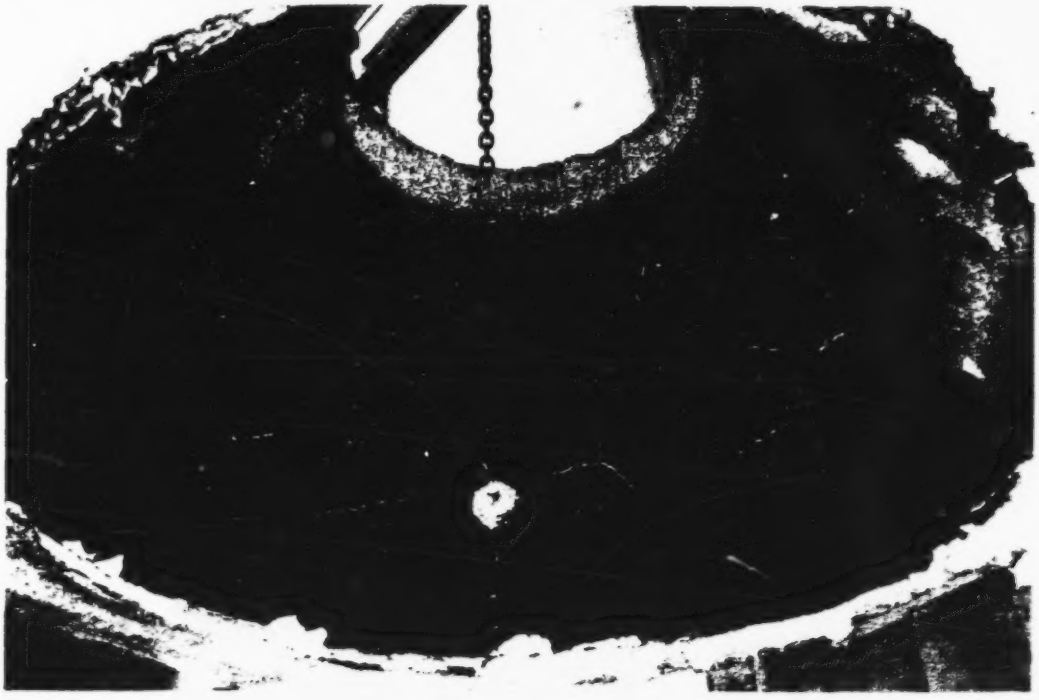


FIGURE F-15: Photograph of the flat roof taken during the digout